Crowd-driven Ecosystem for Evolutionary Design

Final Report

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TABLE OF CONTENTS

TABLE OF CONTENTS ..... **II**

LIST OF FIGUTES ..... **IV**

LIST OF TABLES ..... **V**

EXECUTIVE SUMMARY ..... **VI**

TEAM ..... **VII**

LIST OF ACRONYMS ..... **VIII**

1. TASK OBJECTIVES **1**

1.1. RESEARCH GOALS 1
1.2. APPROACH 1

2. DIFFICULTY DEMOCRATIZING CEM DESIGN, DEVELOPMENT, AND SYNTHESIS **2**

2.1. UNCOVER MECHANISMS TO PROMOTE "GRASSROOTS" STYLE CROWDSOURCING OF CEM DESIGN AND DEVELOPMENT 2
2.2. DEAL WITH SYSTEMS-LEVEL INTEGRATION AND TESTING CHALLENGES 2
2.3. SUPPORT BIOMIMETIC "HARDENING OF THE DESIGN" PROCESS 2
2.4. ENABLE DESIGN REUSE OF BOTH OPEN-SOURCE AND PROPRIETARY MODULES 2
2.5. PROVIDE EASY ACCESS TO DESIGN TOOLS 3

3. GENERAL METHODOLOGY **4**

3.1. BACKGROUND 4
3.2. TECHNICAL APPROACH 4
3.2.1. Overview *4*
3.2.2. Key Features *5*
3.2.2.1. Project Hosting and Management 5
3.2.2.2. Integrated Simulation Environment 5
3.2.2.3. Distributed Service Marketplace 5
3.2.2.4. Authentication and Authorization 6
3.2.3. Software Architecture *6*
3.2.3.1. Architectural Representation 6
3.2.3.2. Architectural Goals and Constraints 6
3.2.3.3. Use-Case View 7
3.2.3.4. Logical View 8
3.2.3.5. Overview 9
3.2.4. Source Information from Confluence *10*

4. TECHNICAL RESULTS **11**

4.1. VEHICLEFORGE FEATURE SET 11
4.2. DESCRIPTION OF KEY VEHICLEFORGE CAPABILITIES 13
4.2.1. Homepage Features *13*
4.2.1.1. Current Challenges 13
4.2.1.2. Latest News 13
4.2.1.3. Website Stats 13
4.2.2. Dashboard Features *13*
4.2.2.1. Dashboard Home 13
4.2.2.2. Public Profile 14
4.2.2.3. Work 14
4.2.2.4. Diary 14
4.2.2.5. Create Project 14
4.2.2.6. Register Server 14
4.2.3. Community Features *14*
4.2.3.1. Community Home 15
4.2.3.2. Members 15

4.2.3.3. Discussion Board 15
4.2.3.4. Resources 15
4.2.4. Marketplace *16*
4.2.4.1. Component Marketplace 16
4.2.4.2. Service Marketplace 16
4.2.5. Projects *16*
4.2.5.1. Project Home 17
4.2.5.2. Components 17
4.2.5.3. Services 17
4.3. QUALITY AND DEVELOPMENT PROCESS 18
4.3.1. Availability *18*
4.3.2. Performance *18*
4.3.3. Security *19*
4.3.4. Maintainability *19*
4.3.5. Usability *19*
4.3.6. Testability *19*
4.4. DEPLOYMENT AND INFRASTRUCTURE OVERVIEW 20
4.4.1. Deployment on the Cloud *20*
4.4.2. Server Dependency Matrix *21*
4.4.3. Deployment Process Flow *21*
4.4.4. Deployment Testing Sequence Diagram *23*
4.5. USER INTERFACE DESIGN 24
4.5.1. Home Page *24*
4.5.2. Dashboard *25*
4.5.3. Community Home Page *26*
4.5.4. Members Page (before Login) *27*
4.5.5. Members Page (after Login) *28*
4.5.6. Discussion Board: Home (before/after Login) *28*
4.5.7. Discussion Board: Forum (before/after Login) *29*
4.5.8. Discussion Board: Topic (before/after Login) *30*
4.5.9. Resources Home *31*
4.5.10. Resources Page *31*
4.5.11. Resources Alternative: View All *32*
4.5.12. Marketplace *32*
4.5.13. Marketplace (Alternative View) *33*
4.5.14. Component Page *34*
5. IMPORTANT FINDINGS AND CONTRIBUTIONS 35
5.1. CONTRIBUTIONS 35
5.2. IMPORTANT FINDINGS 36
6. IMPLICATIONS FOR FURTHER RESEARCH 39
7. STANDARD FORM 298, AUGUST 1998 40
8. TEAM BIOS 41
9. BIBLIOGRAPHY 45

LIST OF FIGUTES

FIGURE 1. CONCEPTUAL OVERVIEW OF THE CEED PLATFORM 5
FIGURE 2. VEHICLEFORGE ARCHITECTURE OVERVIEW 9
FIGURE 3. HIGH-LEVEL OVERVIEW OF VEHICLEFORGE DEPLOYMENT ON THE CLOUD 20
FIGURE 4. VEHICLEFORGE INSTANCE DEPLOYMENT PROCESS 22
FIGURE 5. SEQUENCE DIAGRAM DEPICTING THE PROCESS OF DEPLOYMENT TESTING 23
FIGURE 6. DOME DEFINES ENGINEERING CONSTRUCTS NECESSARY TO CONNECT ENGINEERING AND MANUFACTURING TOOLS 37

LIST OF TABLES

TABLE 1. PRIORITIZED LIST OF FEATURES RANKED FROM HIGHEST TO LOWEST 8
TABLE 2. A LIST OF VEHICLEFORGE IMPLEMENTED CAPABILITIES AND RELATED FEATURES 11
TABLE 3. A LIST OF VEHICLEFORGE ADDITIONAL FEATURES DESIGNED 12
TABLE 4. SERVER DEPENDENCY MATRIX 21
TABLE 5. KEY ELEMENTS OF THE CEED PLATFORM 35

EXECUTIVE SUMMARY

General Electric Global Research and Massachusetts Institute of Technology (MIT) have built and demonstrated a crowd-driven ecosystem for evolutionary design (CEED) to support DARPA's "vehicleforge.mil" program to revolutionize modern-day design and manufacturing. Through this platform, DARPA is looking to enable a global community of experts to design and rapidly manufacture complex systems such as military vehicles, aviation systems, and advanced medical devices. These cyber-physical systems can take decades to develop. The primary goal of this program is to dramatically reduce that timeline.

The CEED crowdsourcing platform will connect data, design tools, and simulations in a collaborative environment to accelerate the design of highly complex industrial systems. The CEED vehicleforge platform allows designers to team up to develop projects concurrently. Developers from different spaces will be able to form design communities and create a common project that will allow them to manage processes as a team and track changes and updates.

Furthermore, the CEED platform provides a marketplace where contributors can choose to expose their ideas to the public either as open source or as IP protected services. One unique feature of CEED is the incorporation of MIT's Distributed Object-based Modeling Environment (DOME)—a simulation "engine" that contributors use to plug in and test simulated components. Users can attach simulation services to explore the behavior of complex systems, and to predict problems earlier to get a better design faster. In his New York Times article, Steve Lohr states that "there are plenty of computer-aided software tools used in design and manufacturing. But the software is often difficult to use and expensive" [Lohr 2012]. With DOME, the vehicleforge.mil program will "allow solo inventors or small teams to tap into those capabilities. A vehicle body and chassis design, submitted as code, could be plugged into the vehicleforge.mil platform and tested for aerodynamics in a virtual wind tunnel" [Lohr 2012].

The exposed design models, or models available for review in this open community, will experience market pressures that ultimately allow for the best designs to emerge. The CEED platform also embeds social media connections to maximize crowd engagement. Within such an environment, experts and non-traditional contributors (crowd) can design individual components or entire systems by reusing, remixing, and building on designs prepared by others. These designs will continue to evolve through a series of reiterative design loops that produce crowd-driven selection pressure including design and performance tests.

TEAM

The CEED team's inspiration comes from MIT's DOME research initiative. In 1995, David Wallace, a professor in MIT's CADlab, coined the concept of "service marketplace" as a paradigm shifting way for predictive integrated system modeling in the design of complex products. Over the next 10 years, a distributed computational infrastructure—DOME—has been developed as an enabling technology for this design service marketplace vision. Qing Cao, now a researcher at GE Global Research, was one of the key personnel on the DOME project while she worked toward her Ph.D. For CEED, the team is expanding DARPA's original requirement of a project hosting and management website to include DOME's service marketplace, which is a key differentiator and enabler for design ecosystems.

Qing and David are the Principal Investigators of this CEED activity. The GE Global Research team has a team of computer scientists and software engineers that bring in extensive expertise in software research and production software development. Benjamin Beckmann is leading the federated authentication and cloud deployment effort. Thomas Citriniti is in charge of the overall software architecture and infrastructure. More information can be found in the team bios section.

LIST OF ACRONYMS

AVM	Adaptive Vehicle Make
CAD	Computer Aided Design
CAE	Computer Aided Engineering
CAM	Computer Aided Manufacturing
CEED	Crowd-driven Ecosystem for Evolutionary Design
CEM	Cyber-electromechanical
DARPA	Defense Advanced Research Projects Agency
DOME	Distributed Object-based Modeling Environment
FANG	Fast Adaptable Next-Generation Ground Vehicle
GE	General Electric
IdP	Identity Provider
IP	Intellectual Property
ISO	International Organization for Standards
MIT	Massachusetts Institute of Technology
SOA	Service Oriented Architecture
SSO	Single Sign On
S3	Simple Storage Service
VOC	Voice Of the Customer

1. TASK OBJECTIVES

1.1. Research Goals

Our research goals are:

- Research and develop key enabling technologies for crowdsourcing the design of complex systems.
- Provide a web-based collaborative design environment enabling the evolution of CEM systems within a crowd-accessible, service exchange marketplace.
- Investigate mechanisms to attract a crowd of productive experts, non-experts, and companies in a cooperative and rewarding ecosystem.
- Facilitate design-cycle incorporation of real-world performance feedback received from dynamic, competitive, and hostile environments.
- Investigate mechanisms to protect the intellectual property (IP) and value within a collaborative crowdsourcing environment.
- Address traditional system integration difficulties associated with scale, complexity, rate of change, heterogeneity, and proprietary information.

1.2. Approach

In order to answer DARPA's call for a collaborative crowdsourcing environment to democratize the design process of complex cyber-electromechanical (CEM) systems, the team developed CEED, which is a web-based collaborative environment to support the crowdsourcing of CEM systems.

Such an environment allows designers to team up to develop projects concurrently. Developers from different locations, backgrounds, and pedigree will be able to form design communities and create a common project space. This space will allow them to manage processes as a team and track changes and updates on their project.

Furthermore, the CEED platform provides a marketplace where contributors can choose to expose their ideas to the public either as open source or as IP protected services. The exposed design models, or models available for review in this open community, will experience market pressures that ultimately allow for the best designs to emerge. This will mirror how designs are vetted in the open market today, but will work faster. It promotes an active evolutionary process to source distributed design components, and submit them to aggressive functional and system testing on-the-fly in a reiterative biomimetic "hardening process."

The CEED platform also embeds social media connections to maximize crowd engagement. When completed, the software developed under the contract will be open-sourced and used to support portions of vehicleforge.mil.

2. DIFFICULTY DEMOCRATIZING CEM DESIGN, DEVELOPMENT, AND SYNTHESIS

A collaborative crowdsourcing environment to enable the democratization of CEM design is very different from the democratization of software design. Several key challenges exist.

2.1. Uncover mechanisms to promote "grassroots" style crowdsourcing of CEM design and development

Although open-source crowdsourcing environments have significantly benefited software development, the art of crowdsourcing for innovation, quality, and cost efficiency has not been successfully translated into hardware design and development, especially for CEM systems. Motivations for skilled individuals and companies to participate (e.g., altruism, community sense, free-riding, effort, etc.) need to be explored to build mechanisms to attract and sustain a crowd of CEM designers.

2.2. Deal with systems-level integration and testing challenges

Typical CEM design involves multi-domain, multi-physics modeling, analysis and simulation. Designers of these systems use complex chains of heuristics to model the interaction between different components. It is the intent of this work to develop collaboration and design techniques to enable advancement of crowd-oriented design. To make this possible, any crowd-sourced CEM collaboration system must be responsive to the specific challenges of the system domain.

Complex system integration of any kind relies on well-defined and understood interfaces between system components. The development of software systems is simplified because well-defined interfaces are readily available for integration. By comparison, CEM design is extremely difficult because of the integration of heterogeneous models, data, computations, and tools involved is complicated. This is partially due to the size, complexity, and evolving nature of the models in hardware design. It is also due to the need for different tools, data management, and representations; and to the fact that all required data are not globally available, for logistical or proprietary reasons (Cutkosky *et al.* 1996). Generic integration platforms that could support globally optimizing the system-level CEM design and testing are still to be developed.

2.3. Support biomimetic "hardening of the design" process

Product design and development is a highly iterative process. The combination of intended or accidental variations, from iteration to iteration, commonly exposes design flaws and occasionally reveals innovation. This process, in the hands of the crowd, can enhance the creation of robust designs, exceeding limitations of processes that solely depend on deterministic models or elaborate specifications.

2.4. Enable design reuse of both open-source and proprietary modules

Typical open-source crowdsourcing participants are drawn from a collection of amateurs, volunteers, and experts from small business (Howe 2006). Unlike software systems, however, the design of a complex CEM system often involves the need for intensive engineering expertise, expensive design and analysis tools, and specialized test facilities. A majority of these types of professionals with both the desired expertise and training, and with access to the required tools and facilities, resides within the proprietary walls of industry. Uncontrolled release of proprietary knowledge in the form of documentation, schematics, or computational models is currently inappropriate without a major change in how this information can be safely shared with its value retained. Legal restrictions aside, existing compensation and cooperation models and other technical limitations will negatively impact the crowd participation paradigm if open-source models are the only way to contribute.

2.5. Provide easy access to design tools

The cost of the design tools represents a substantial challenge. A designer must be afforded suitable tools, representations, simulations, heuristics, or models to fulfill design requirements and handle complexities. However, this affordance drives designers toward specialized products whose availability and costs limit the design's potential and restricts its community of users. This gap must be overcome to democratize CEM design.

3. GENERAL METHODOLOGY

3.1. Background

The CEED platform is analogous in many ways to project management systems like SourceForge (http://sourceforge.net/) and GitHub (https://github.com/). Traditionally, these types of systems allow globally distributed individuals to collaboratively develop software. However, the modernization of computer aided drafting (CAD), engineering (CAE), and modeling (CAM) has allowed an engineering team to be globally distributed. Furthermore, computer aided virtual environments allow the engineers to share and iterate on work products to produce robust, cost effective, and essentially more valuable designs.

Project management platforms designed for software development enable a transparent, iterative design process. This process has proven successful for software development, and its application to traditional engineering is promising, even for large-scale designs.

However, a software development project management system would not be adequate for engineering without modification and integration into an engineer's daily work process. Adding another system to an engineer's work process only adds value if it enhances the engineer's ability to complete the assigned work.

The CEED Platform is architected, designed, and built to seemly integrate with existing engineering practices. It allows for the sharing, integration, storage, and retrieval of engineering artifacts, including parametric models, test results, and other data essential to the engineering process.

To achieve successful delivery of the CEED platform within the one-year time frame, the team leveraged an agile development process. This process was driven by user stories developed collectively by computer scientists, engineers, and program managers. These stories helped to identify common themes that are present throughout the platform, and ambiguous concepts that could be problematic for a cross disciplinary team.

3.2. Technical Approach

3.2.1. Overview

The CEED platform was designed and developed as a crowdsourcing collaborative environment to democratize the design process of complex CEM systems.

Figure 1 is an overall concept chart of the CEED platform.

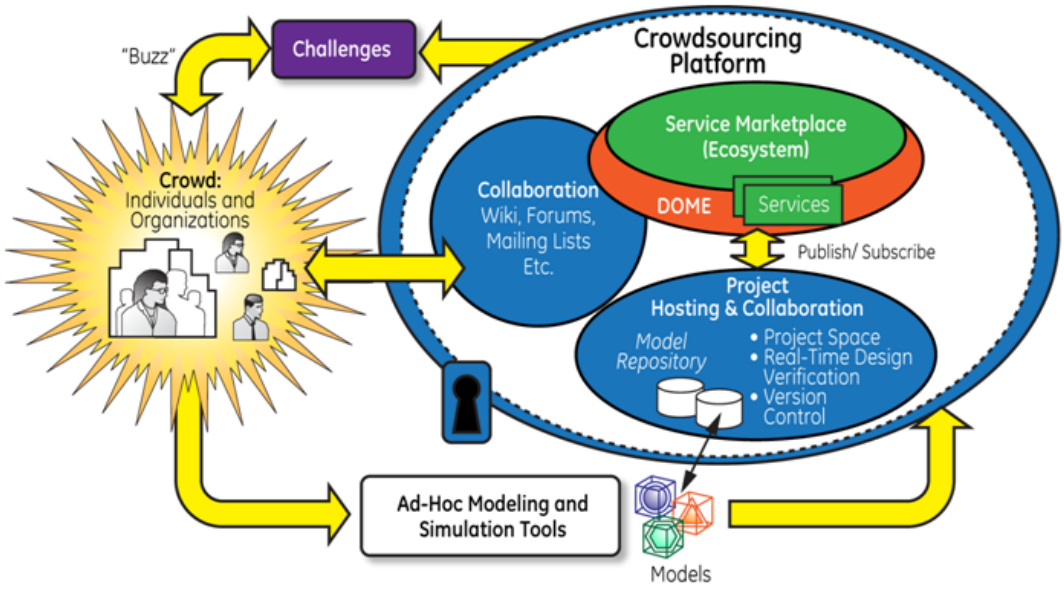


Figure 1. Conceptual overview of the CEED platform

3.2.2. Key Features

3.2.2.1. Project Hosting and Management

An off-the-shelf open-source project management platform can serve as a collaboration environment that allows geographically distributed contributors to collaborate on a common goal. The platform assists in the management of design and development efforts by providing a variety of collaboration tools integrated into a single platform where a project can be created and the collaborative tools are immediately available. Project discussions are supported through forums, mailing lists, message boards, and micro blogging streams. Furthermore, generation of project-specific content, such as documentation or tutorials, is supported in a project's wiki. Lastly, the platform provides an integrated version control repository. These collaboration tools support the self-organization and archival of project-specific information.

3.2.2.2. Integrated Simulation Environment

CEM design platforms need to address system-level integration of components represented by cross-platform, multi-domain, multi-physics models, analysis and simulations. MIT's DOME is a computational infrastructure for this purpose. DOME provides a foundation of service definitions and mechanisms that allow designers to define how their model or process can be described, connected, and executed through a distributed service oriented architecture (SOA). DOME enables a platform upon which a community can build integrated design scenarios with crowd contributed computational resources.

3.2.2.3. Distributed Service Marketplace

CEED augments the platform with a distributed design service marketplace. The distributed service marketplace allows individuals and companies to:

- Exchange models, services, and opportunities.

- Integrate nontraditional team members who can freely express opinions, vote, test, and distribute information.
- Build a reputation as a CEM expert.
- Foster a healthy ecosystem through controlled design selection that penalizes poor designs, rewards robust ones, and potentially reveals unforeseen and unplanned features.
- Facilitate the democratization of hardware design.

3.2.2.4. Authentication and Authorization

Additionally, the CEED system is augmented with export controls, private branching, and federated authentication and authorization capabilities. These features support user and project security. The security solution is built on freely available and established open-source software such as:

- Shibboleth: http://shibboleth.net/
- OpenLDAP: http://www.openldap.org/
- Kerberos: http://web.mit.edu/kerberos/

Users from multiple organizations will be able to gain access to specific projects by authenticating to their home institution's identity provider, which in turn provides a limited set of user attributes required for authorization.

3.2.3. Software Architecture

3.2.3.1. Architectural Representation

The principal objective of the vehicleforge.mil effort is to generate an open source development collaboration environment and a website for the creation of large, complex, cyber-electro-mechanical systems by numerous unaffiliated designers. In short, this is a large forge-based site where designers can work, post, and design CEM systems in a crowd sourced environment.

To satisfy the requirements for such a large distributed system, an industry standard tiered architecture was chosen. This architecture pattern defines the standard tiered system pattern:

Presentation tier: Handles all user interactions and facilitates that need to handle multiple clients, various visualization paradigms, and abstraction from the logical tier.

Orchestration tier: Web server endpoint for requirements such as load balancing, caching, authentication/validation, and redirection.

Services/Logical tier: Handles exposing specific business and process logic to facilitate the scalability needs and loosely coupled logical components.

Operations/Data tier: Exposes all low level data and remote services to the core platform.

The main aspects of the system will be described in the implementation view. The overall architecture diagram and its separation into design pieces will be explained.

3.2.3.2. Architectural Goals and Constraints

The DARPA project has placed several constraints on the development of the system. The following constraints directly impacted the architecture:

- "Offerors should propose, as part of their work plan, affirmative steps for the open source promulgation of all source code, executables, documentation, and test use cases for operating vehicleforge.mil."
- "Information assurance controls sufficient to protect export controlled and contractor proprietary information in accordance with Department of Defense, Department of State, Department of Commerce, and any other statutory or regulatory requirements or best practices"

The requirement for open source and release of all executables to vehicleforge.mil has led to several design choices and architecture modifications. While most enterprise design patterns are available in open source versions, the installation and maintenance of these systems is challenging due to lack of dedicated support and documentation. The final deliverables need to include maintenance and installation material and, without guidance from the OpenSource providers, the final deliverable will be as complete as possible.

The IA requirements were defined as the project progressed. Due to the open nature of the system combined with the need to include ITAR materials, the definition of the controls needed has morphed over time. As controls have been explained and refined, the platform architecture has been modified to accommodate these new constraints. This "as you go" approach may cause difficulties in that some new constraint may lead to drastic changes in the architecture to support the new requirement.

3.2.3.3. Use-Case View

The major functionality of the system hinges on the interaction of the user types listed below with the vehicleforge website. The users and key use cases are:

- Unauthenticated user (people who want to browse the website)
- Authenticated user
    - New user
    - Existing user
    - Model builders: someone building model definitions or services using the system
    - Assemblers: people who want to integrate designs
    - Designers: people who want to investigate models to satisfy a design
    - Validators/curators: people who check the validity of a model/design
    - Viewers: high level users who have a stack in the design (PM, business leads)
    - Model providers/suppliers: users who want to expose existing models/designs to the community
    - Mentors: users who answer questions and provide guidance on specific topics to select users
    - Spies: users who are trying to steal IP and internal design specifications

There is a prioritized list of what these users will want to accomplish and this defined the feature set that needs to be realized by the platform. The feature set from all users was then aggregated and ranked according to number of uses in all user categories.

Table 1 represents the highest ranked features. This table is used in project planning to define the next set of work items.

Table 1. Prioritized list of features ranked from highest to lowest

Feature	Rank
Search for a model based on (usability/ratings/popularity/specification/author/Free/my own criteria)	17
Comment (make, share, read reviews)	12
Tutorial (how to build a model, assemble models, publish a model, use the system)	7
Share and use/publish models	7
Test bed (industry standard test, test suite) system	6
View and browse all models, and by categories	6
Create and find communities	6
Validation (specific to a project)	5
Share (share model found on the marketplace, send to, print, submit result, homework assignment)	5
I want to be paid	5
Automate model connector, 3rd plugins, and current tool integration	4
Tracking models and get notified with changes	4

3.2.3.4. Logical View

The architecture of the platform is patterned after an N-Tier design. This system has been broken into four tiers—presentation, orchestration, services, and operations—as depicted in Figure 2. This design will allow for logical separation of the platform infrastructure to facilitate an open and pluggable framework. The goal is to isolate the major needs of the website and create industry standard links between them. In this way, plugging in a different provider of the feature set can be accomplished with minimal effort.

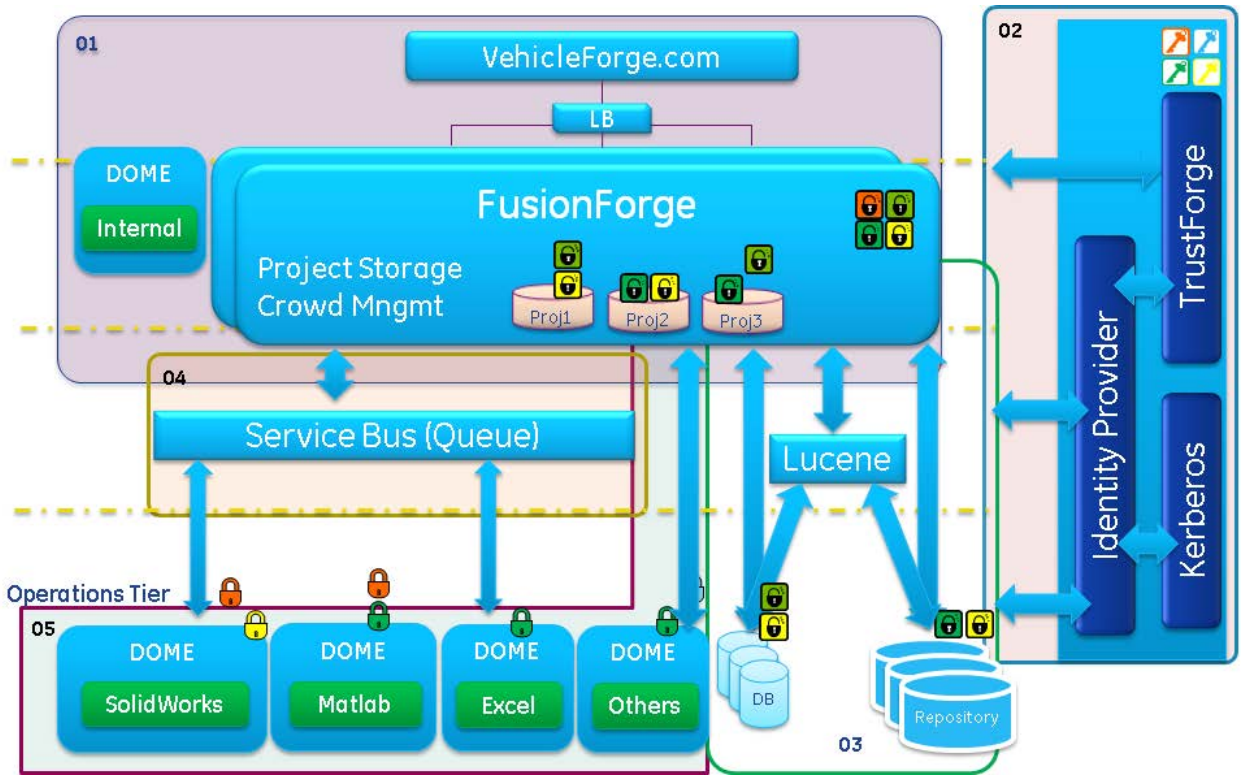


Figure 2. vehicleforge architecture overview

The subcomponents identified above are detailed in accompanying documentation that explains the design decisions and application links that facilitate the flow of data through the system.

3.2.3.5. Overview

The details to each of the design areas above are documented in accompanying design documents.

00-Overall Design: The overall design document.

01-Presentation Tier: This document will describe the vehicleforge website and design decisions concerning all presentation tier development. This includes the underlying object model, database Schema for core components, integration with web components, and deployment requirements.

02-Security: This document will cover the security platform including design decisions with respect to user identity, communication with TrustForge, and availability of an apache mod to facilitate all needed security communication for any included service.

03-Data Storage and Meta Data: This document will cover the data base software as well as the schema used in the core functionality of the system as well as usage of the Amazon's Simple Storage Service (S3) as the collaborative storage mechanism. It will also include the design and integration with the repository software including storage and setup.

04-Services Tier: This document will cover the service bus architecture with respect to communications to and from distributed services in support of the service marketplace. This includes design decisions about product use and feature sets as well as security issues.

05-DOME Service Marketplace: This document will describe the integration of DOME services into the vehicleforge website as well as the communication and security needed for providers to supply access and restrict access to their distributed services.

06-Deployment Scalability: This document will detail the layout of the Amazon instances with respect to where the various providers are provisioned as well as the phased approach to accomplishing the goal. It will cover the installation, setup, maintenance, and security aspects of the design.

3.2.4. Source Information from Confluence

All the information from the Confluence system is included in the technical package submitted as part of this project deliverable.

4. TECHNICAL RESULTS

The main technical outcome of this project is the full implementation of vehicleforge. This section, reports on the various technical aspects of this project including the vehicleforge feature set, description of the main functionality, quality attributes of the system, and the verification and validation approach.

4.1. vehicleforge Feature Set

The website contains a host of features that satisfy each of the three tasks stated in the Statement of Work.

- Task 1 – Develop vehicleforge platform framework, and develop project hosting and collaboration components.
- Task 2 – Develop the vehicleforge service marketplace.
- Task 3 – Integrate various components and test vehicleforge platform.

Table 2 lists the capabilities and related features that were identified at the beginning of this project, and have been implemented in vehicleforge.

Table 2. A list of vehicleforge implemented capabilities and related features

Capability	Related Features
User Management	
	User registration
	Content moderation
Security and Access Control	
	Export control
	Customizable permission and access control
Project Management	
	Create/update project
	Make project public/private
	Branching (public/private)
	Revision control: check-in and check-out of content
	Specify keywords/tags/category
	Document management
	Task tracker
	Bug/Issue tracker
	Project activity/history
	Time tracking and reporting
Collaboration Spaces	
	Blog: diary feature
	Poll/survey
	Wikis
	Mailing list
	Community page
Social Networking	
	Activity stream/newsfeed
	Crowd-rating and voting
	Commenting (project, model, user)
	Tagging project

	User profiles
	Friends/follow
	Subscriptions/messages
Reporting & Analytics	
	Real-time dashboard via Google Analytics
Sharing/Co-creation	
	Publish/share project
	File release
	Execute model through web UI
	Visual way to connect models
	Validation
Productivity	
Search	Site-wide search of content
	Search project (by name or category)
	Search model (by name)
	Search user (by name)
	Search skills
	Search community
Browse	Browse projects
	Landing page to view projects
	View a project (high level summary, its performance and reviews, specification)
	Browse services and components through project
Association	
	Graphical view for association between components

Additionally, exploratory design has been conducted to identify more features that could enhance the user experience, website utility, and functionality needs of users. Table 3 contains a list of features for which a user interface design has been developed without backend functionality.

Table 3. A list of vehicleforge additional features designed

Capability	Related Features
User management	
	User roles
Collaboration spaces	
	Forum
Social networking	
	Tagging component
Sharing/Co-creation	
	Downloadable package
	Simple way to build model to test an idea
	Integrate models
	Plugins for third party tools
Productivity	
Browse	Browse services and components through marketplace
Association	
	Association between related projects

4.2. Description of Key vehicleforge Capabilities

The vehicleforge website was designed to reflect the approach the government uses to release design challenges to the crowd as a solicitation mechanism for building the next generation military vehicles. The website design is based on the principles of online collaboration, networking, and crowdsourcing. The overall goal is that members (users of the website) will be able to team up with one another—regardless of location and prior acquaintance—in order to develop virtual project models that can be submitted as entries to the design challenges. The vehicleforge website provides the framework for this type of collaboration as well as additional tools and software to help build project ideas.

The following sections describe the various elements of the vehicleforge website and the corresponding features implemented.

4.2.1. Homepage Features

The homepage is the vehicleforge starting point; it gives an overview of the vehicleforge website and how the website can be used to develop project ideas. It serves to orientate users to different parts of the website and gives a general idea of website activity. For a user who is new to the website, it is a good base to come back to. However, as a user becomes more accustomed to vehicleforge and is active within projects, the dashboard is recommended as the base for website navigation.

4.2.1.1. Current Challenges

Information about project ideas and cash prizes for various challenges is displayed here. The user can read up on design challenges that have been released to the public. The user can start a project entry for the challenge or see if there is an existing team to join based on what interests them.

4.2.1.2. Latest News

The user can learn about the most recent things members have been up to on the website. By clicking on one of the news items, the user can get more related information. By seeing what others are doing on vehicleforge, users can get ideas for employing the website and what activities to get involved in.

4.2.1.3. Website Stats

A summary of whom and what are on vehicleforge is shown here. Links can be used to explore different features and pages on the website. Users are given the opportunity to come across an interesting project or connect with other members.

4.2.2. Dashboard Features

The dashboard is a home base that is unique to the interests of each individual user. This page allows the user to track their activity on vehicleforge. From the dashboard, it is easy to navigate to the parts of the website the user will employ the most, and it gives quick access to projects, discussions, and other activities.

4.2.2.1. Dashboard Home

The purpose of the dashboard home is to serve as a personalized streamed newsfeed where the user is able to choose to receive updates on certain information and parts of the website.

- **Manage:** This stream displays any recent activity related to the user's projects and components they are working on. It allows the user to keep track of what teammates have accomplished and if other members expressed interest in the user's work. Additionally, the side bar consists of a summary of what the user is involved in to easily manage interests.

- **Subscribe:** Throughout vehicleforge, there is the option of subscribing to different members, projects, components, and services. The user's stream contains recent notifications and updates relating to these subscriptions. This allows the user to track if a component from the market place has been updated or if another user has created a new project of interest to join.

4.2.2.2. Public Profile

The public profile tab is where the user displays information about themselves to other members.

- **Edit:** By activating the edit mode, the user can change the profile picture and create introductory text.
- **Present:** The profile shows a user's work on vehicleforge and the user's member reputation. It allows users to connect to work on projects together, or simply make a new contact.

4.2.2.3. Work

The work tab is a way for the user to monitor the projects they are involved with.

- **Artifacts:** Allows the user easy access the projects they are a part of in order make changes and further the project design.
- **Tasks:** Allows the user to manage a "to do" list to stay on schedule and make sure any outlying tasks are finished.

4.2.2.4. Diary

The diary tab is a place for the user to write out their thoughts while working on vehicleforge. The user can revisit what was written by selecting the entry title at the bottom of the page.

- **Reflect:** The diary feature can be used to make quick notes about an interesting component on vehicleforge, to write about what was accomplished on a project, or reflect on an interesting article relating to a design challenge.
- **Share:** By checking the "is public" box, the diary can be used as a sort of blog or mailing list that will send entries to members who are following the user.

4.2.2.5. Create Project

The create project tab is the portal through which the user can lead a design team and build a virtual project.

- **Grow:** The user has the chance to start projects, be the leader, assemble a team, and be recognized for innovation and expertise.

4.2.2.6. Register Server

The register server tab is where the user can connect a vehicleforge account to external servers to increase access to different resources.

- **Expand:** By registering other servers, additional software and tools can be accessed to create a more sophisticated final product.

4.2.3. Community Features

The community page is the social hub of vehicleforge. It is through this page that users connect to peers and scout out projects, components, and challenges to help develop ideas. Like any larger social website,

the types of interactions and uses for the community page are limited only by the user. The user is encouraged to find creative ways to connect with other members and move projects forward.

4.2.3.1. Community Home

The home tab is where the user can stay up to date with trending and the latest challenges, projects, and components on vehicleforge.

- **Challenges:** Users can find inspiration or a big cash prize by getting involved in a challenge and joining in on the competition.
- **Projects:** The latest projects are likely to be looking for members to recruit. Browsing through popular projects is a good way to get new ideas and see what interesting things others are doing.
- **Components:** Users have the opportunity to be the first to try out a latest component for a project or scout out component creators to find an experienced designer for their team.
- **Sidebar:** The sidebar gives the user quick access to interesting discussions and resources that may help answer questions or give food-for-thought.

4.2.3.2. Members

The members tab allows the user to see who else is on vehicleforge and connect with users of interest for further networking and communications.

- **Search:** The user can search for specific members or by skill set to fill a hole in a team.
- **Browse:** The user can browse the member pages to make a new connection or re-connect with someone. Clicking on a member's name activates a pop-up that describes their particular skills.
- **Learn:** By clicking on the "view profile" link in the pop-up, the user can view information about a member's recent activity, projects, and on-line reputation.
- **Connect:** To join a member's project, recruit a member for a project, or just make a networking connection, the user can leave a comment on the member's profile or start a private message conversation. To be updated on a member's contributions to vehicleforge, the user can also subscribe to that member and receive notifications via the dashboard.

4.2.3.3. Discussion Board

The discussion board is where users can ask specific questions, get feedback on work, or simply start a conversation on a topic of interest.

- **Browse:** The user can view questions and conversations other members are having or use the forum navigation bar to sort through specific topics. It is possible the user will find that their question has already been answered or may unexpectedly find some useful information.
- **Learn:** The user can start or join an existing discussion to get questions answered or share expertise with those who need it.
- **Connect:** The discussion board is a good place to meet and interact with other members. It is a way for the user to thank a helpful member or recruit a member for a project.

4.2.3.4. Resources

The resource page is a member-run center where users can find additional help to better navigate the website and complete certain actions.

- **Search:** The user can find information by searching for a specific term, using the browse resources links, or seeing what resources are most used or recently updated.
- **Learn:** The getting started and FAQ resource pages are a good place for new users to get oriented with the website. Experienced users can use the technical resource pages to solve more complex problems.
- **Teach:** The user can create a page or edit an existing page to address a topic that many users might be having trouble with or provide information about something missing from the resource center. Sharing expertise is a way for the user to boost their member-rated reputation and find more projects to join.

4.2.4. Marketplace

The marketplace allows the user to reach out to others in the vehicleforge community. The main page design was inspired by GrabCAD and GitHub. Users can share models and ideas with others, as well as download other member's components for their own projects. What differentiates the CEED marketplace from GrabCAD or GitHub is the simulation engine "DOME" embedded in the marketplace. The user can plug-in and execute simulation components on the CEED marketplace to see how their design interacts with other parts of the system. The marketplace is what makes crowdsourcing and rapid development possible—it is the center of collaboration for vehicleforge.

4.2.4.1. Component Marketplace

The user can upload a component for others to see, or search through various components to find one that could further aid the development of their project. This will expedite the project development process; for example, if a project uses a CAD to model a system that includes a pulley, it would be much easier to find one that was shared in the marketplace rather than designing one from the beginning.

- **Find Components:** This search bar can be used to narrow down the types of components within the library. After clicking on a specific model:
  - **View Component:** More detail is given for the component.
  - **Add to Project:** The user can click here to add a component to a project.

4.2.4.2. Service Marketplace

The user can run simulations to test different components in a virtual, accurate manner. Services are a large part of why product development can be distributed to people who are apart from each other geographically. Before this progress, much time and money was required to produce many prototypes; this service allows the cost of engineering modeling programs to be cut with the use of open source software. Without these simulations, it is difficult to tell if the digital design will survive the physical world with varying temperatures and loads.

- **Find Services:** The user can narrow a search to figure out how to test models remotely and decide what to test on a component (add dynamic simulations, validations, analysis, etc.).

4.2.5. Projects

The projects page is where the product development work is organized. This is how the process of development without the physical presence of teammates is possible. Once registered, users have access to projects they are involved in, as well as projects they are following.

The user can click on a specific project to show various tabs under the project.

4.2.5.1. Project Home

Get an overview of the project here.

- **Photo Gallery and Activity section:** The user can upload photos of the project to be seen by others for a better visualization of the goal. The activity section is where other members of the community can share their comments on the project. It also shows the user's progress by publishing different steps taken on the project (adding a new component, testing it with a service, etc.).
- **Follow Us:** There are various ways to track a project of interest online through other social media (namely RSS, Facebook, and Twitter) as well as on the vehicleforge website itself. Clicking "Subscribe" will give the user updates about that specific project on their dashboard.
- **Our Team:** The user can invite other members to join a project, as well as see all the people involved in the project listed.
- **Similar Projects:** vehicleforge presents a feature where it orders other similar projects on the side of the project home page. This allows the user to seek inspiration by quickly accessing other similar projects.

4.2.5.2. Components

This shows an overview of all the components that are used in a project.

- **Find Components:** If there are many components in a project, this search bar allows the user to find a component efficiently. When a component is clicked, an overview of information is displayed:
  - **Files:** This shows documentation on a specific component (visual models, text, etc.). The user has the option to "Get Access," which allows the user to transfer files between their personal desktop and the shared vehicleforge project page.
  - **Edit:** The user can change any information about the component here. Additionally, the user can add a sub-component to the component.
  - **Services:** This shows the various services that have been tested on a specific component.
  - **Tags:** The user can organize the component further by tagging various features and uses within the component. Later, all components with the same qualities can be seen listed in one place without having to go through all the components separately.

4.2.5.3. Services

This is where the user can test projects with various simulations or tools. (See Component Marketplace => Features => Services.)

- **Browse Services:** This is where all the services that have been used for a specific project will appear. Clicking on a specific service will give for more information and detail about the service. "Service Subscriptions" lists services from project components as well as from the marketplace. "Your Services" lists the services that the user has shared by uploading them from DOME.
- **Register a Service:** This is where the user can upload a new service from DOME for another type of analysis on a certain component. To register a service in a specific project, the user must:

- Choose the server for available DOME file
- Browse and select the correct DOME folder, model, then interface

Once a service is registered, a service data box below will pop up that allows the user to:

- **Share Service:** The user can share a service with others in the community through the marketplace.
- **Integrate Services:** The user can create a new composite service by assembling instances of existing services, and then connecting their input and output parameters. This new service is called an "integration service", and its internal parts "component services". By connecting inputs and outputs between component services, the user establishes how the data will flow through the new integration service. Since all inputs and outputs must be accounted for, any remaining inputs and outputs from the component services determine by default the new integration service's input and output parameters.

4.3. Quality and Development Process

Besides the implemented features in vehicleforge, a lot of focus has been put on the overall quality of the system in terms of its key quality attributes and the process by which it was architected, designed, and developed. From a quality perspective, this report outlines key quality attributes that capture DARPA's requirements as well as those most relevant to this type of system. Namely, architecture decisions and design choices critical to the system's availability, performance, security, maintainability, usability, and testability are addressed.

4.3.1. Availability

vehicleforge's services are deployed on Amazon's cloud. To address availability, redundancy, and resilience, they are deployed across four different availability zones. For the purposes of this project, the database management system is not redundant. However, the need to reboot the database is mitigated through a notification mechanism that alerts the system administrator that the database is down.

To limit the database exposure to external attacks, the following tactic is adopted:

- Users have no direct way to control database because it is deployed behind the PHP server with restrictive communication rules.
- Penetration testing is carried out to ensure that no potential holes exist that may jeopardize the system.

The document storage uses Amazon's S3 (Simple Storage Service)—a highly available storage capability with a service level agreement specifying 99.99999999999% (11 9's) availability.

The DOME server is deployed in such a way that it has no external access. A web service has been created to manage querying status, starting, and stopping the internal DOME server.

4.3.2. Performance

Various download tests were performed from Oregon to Virginia and all the requirements specified in the BAA were easily exceeded. Load testing with a single user and multiple users (~20 user per webserver, very aggressive users with no think time between clicks) was performed.

Webserver fail-over tests were performed and were all successful. The auto-scaling feature provided by Amazon's cloud environment proved to be a key architecture decision.

4.3.3. Security

A key architecture decision has been made to use a federated access control mechanism as a security tactic. vehicleforge uses Shibboleth identity Provider (IdP) to securely communicate a user attributes to a service provider. It only passes the information that is deemed "required" for granting access to the services requested. This technology maps well to other single sign on (SSO) system, which is used internally at GE.

Other security tactics used in vehicleforge include:

- The website is HTTPS-enabled; it supports encryption of all connections to load balancer.
- Inter-security group insulation makes it so the system does not allow access to machines from non-approved sources.
- Data-at-rest in S3 buckets is encrypted automatically.
- Almost all IA controls specified by government terms have been satisfactorily implemented in vehicleforge and in the supporting infrastructure and services.

4.3.4. Maintainability

vehicleforge was designed to be a highly maintainable system. Consistency from the requirements document to architecture specification to design artifacts to code has been preserved. Architecture documents have been updated throughout development, and mostly reflect the original design. An ISO standard for software design and architecture documentation was followed. A support tool (i.e., Confluence) was used to manage much of the maintenance/development documentation.

The delivered technical package includes read-me files at all levels of the directory structure, step-by-step instructions, and extra information. Tutorial material has been developed to bring new users and developers up to speed quickly on the system's capabilities. In addition, configuration management and documentation are also included.

4.3.5. Usability

In terms of usability, the system has the following:

- Context-aware help (tooltips and on-page help) which removes the barrier of going to a different page to find help
- Brief help, but can link to more detailed information
- Tutorials
- User experience (i.e., Twitter bootstrap website styling package)
- Organizing complexity (the dashboard is a central location to access information and controls)

4.3.6. Testability

Testability is important to ensure that the system is changeable and its use can evolve as its users identify new ways to use the systems. Therefore, it is important to build a system that can be tested easily once a new change, a fault, or a new version is rolled out. The team used a set of tools that are standard within GE such as JIRA, Confluence, and Bamboo. Historic documentation from these tools makes vehicleforge a manageable system in terms of testing it.

Other quality assurance techniques have been employed in terms of the process followed by the team to develop this platform namely:

- An agile approach to development with short iterations and daily stand-up meetings that allowed the team to uncover and address design and code defects as they arise.
- Employment of collaboration tools such as JIRA to track user stories, issues, bugs, and backlog prioritization; and Confluence to share all related artifacts among the team members.
- Continuous integration and testing enabled by the Bamboo testing environment.

4.4. Deployment and Infrastructure Overview

4.4.1. Deployment on the Cloud

Figure 3 shows how code changes are affected on deployed systems in the cloud.

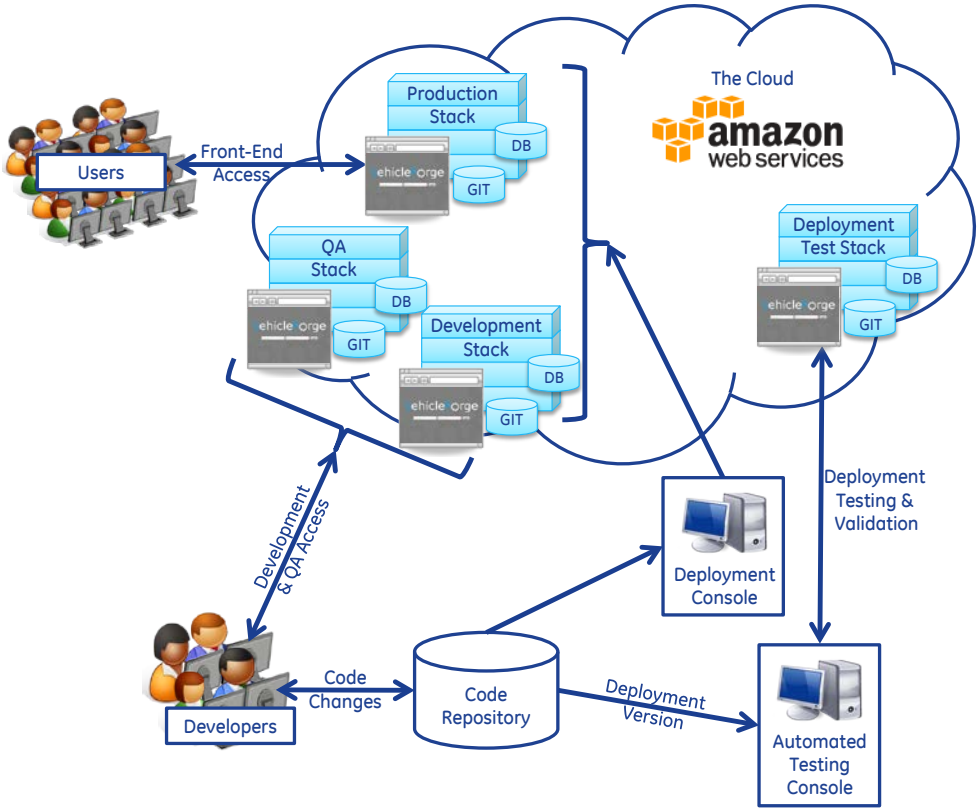


Figure 3. High-level overview of vehicleforge deployment on the cloud

- Developers commit code changes and changes to configuration files on the code repository (SVN).
- Stacks can be started and stopped by an administrator from a deployment console that has the necessary deployment scripts (also in the repository) and requisite tools/applications.
- The deployment console will check all of the necessary configuration information out of the repository for a specified revision number, will package it, upload it to a storage location (e.g. S3 bucket), and will configure all of the cloud resources (via Amazon CloudFormation).

- A testing console has also been developed to expose some of this deployment functionality for automated tests.
- A production stack allows access to a stable release of the website for users, while development and QA stacks are used in development.

4.4.2. Server Dependency Matrix

Table 4 shows the dependencies between the various servers that are deployed as part of the vehicleforge system.

Table 4. Server dependency matrix

Server \ Depends On	PostgreSQL DB	Kerberos	Shibboleth IdP	DOME Server	Solr	GIT	Webserver
PostgreSQL DB					X		
Kerberos							
Shibboleth IdP	X	X					X
DOME Server							
GIT							
Solr	X						
Webserver	X	X	X		X	X	

Xs mark a dependency. The server instances listed on the left side are dependent on instances listed along the top if an X is present.

Here, a server type A is dependent on server type B if A requires some information or file from B upon start-up. There is currently a bi-directional dependency between Shibboleth SP that runs on the webserver and the Shibboleth IdP server. This is currently resolved manually after the stack starts up by restarting processes on each of these servers.

4.4.3. Deployment Process Flow

The following steps describe the process through which an instance of vehicleforge is deployed on the cloud. These steps are depicted in Figure 4.

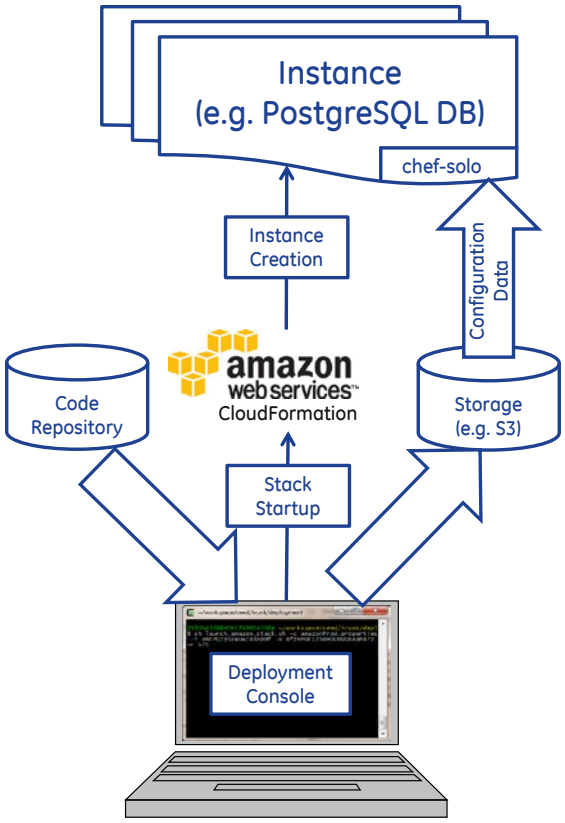


Figure 4. vehicleforge instance deployment process

Step 1: From the deployment console, an administrator initiates the deployment script that specifies a revision number from the repository to use as the deployment base.

Step 2: The script checks out the pertinent configuration files from the repository and packages them in a S3 bucket.

Step 3: The script then initiates the stack-launch by accessing the Amazon CloudFormation API via the command-line tools.

Step 4: Amazon CloudFormation creates and initiates the configuration of several stack resources:

- PostgreSQL Database Instance
- Kerberos Server Instance
- Shibboleth Identity Provider Instance
- DOME Server Instance
- GIT Server Instance
- Solr Server Instance
- vehicleforge Webserver Auto-Scaling Group

Step 5: Each instance is configured using Opscode Chef-Solo and several recipes are developed for this project.

4.4.4. Deployment Testing Sequence Diagram

This sequence diagram (Figure 5) illustrates the communication sequence for deployment testing via a testing console.

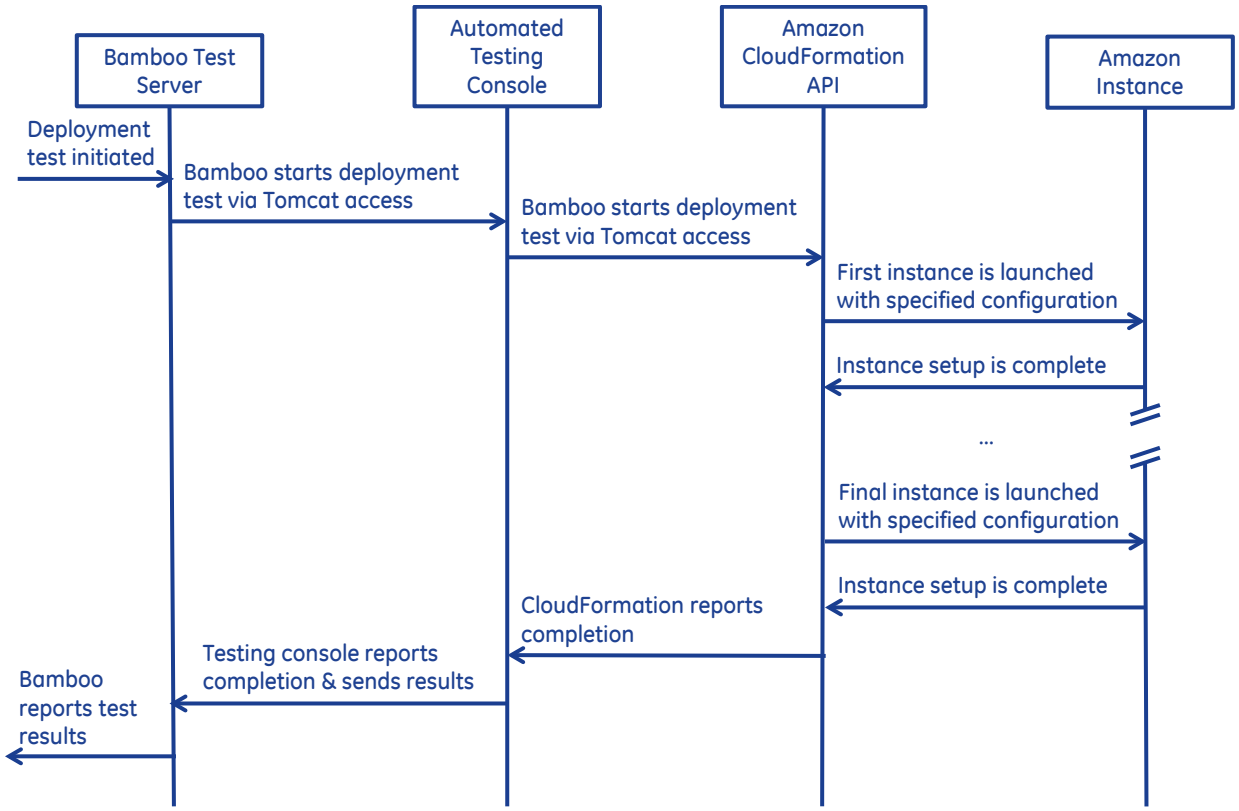
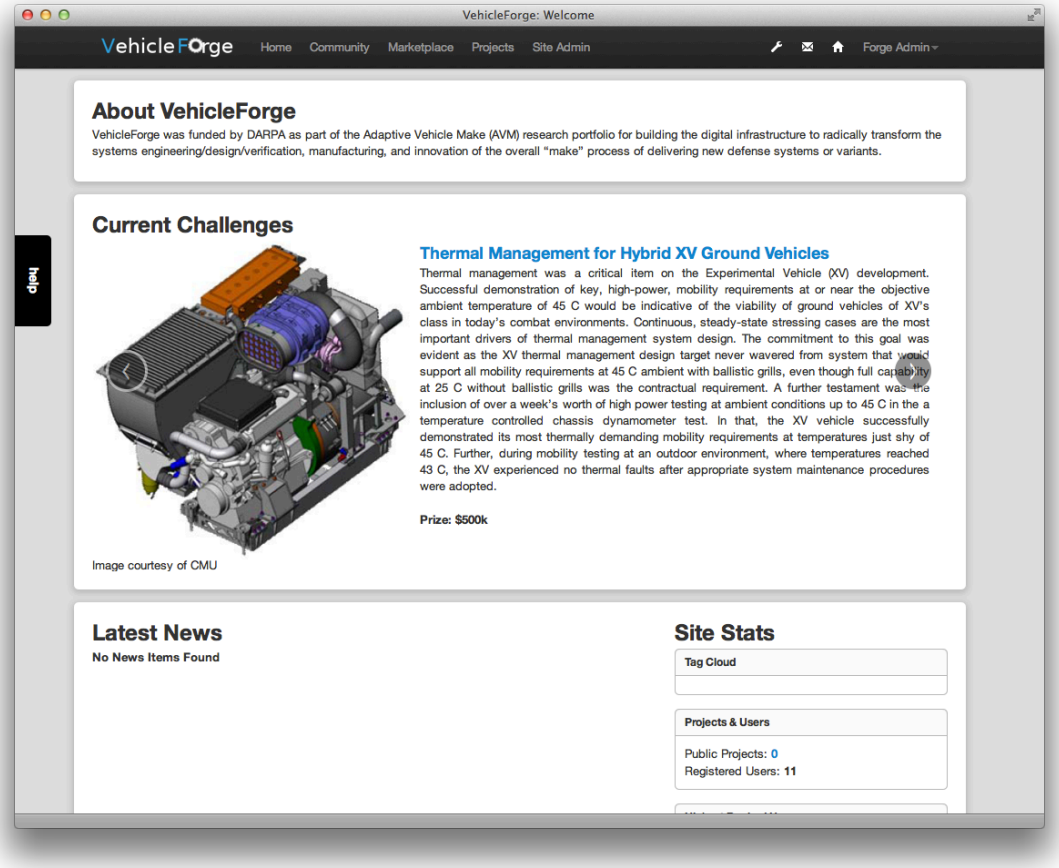


Figure 5. Sequence diagram depicting the process of deployment testing

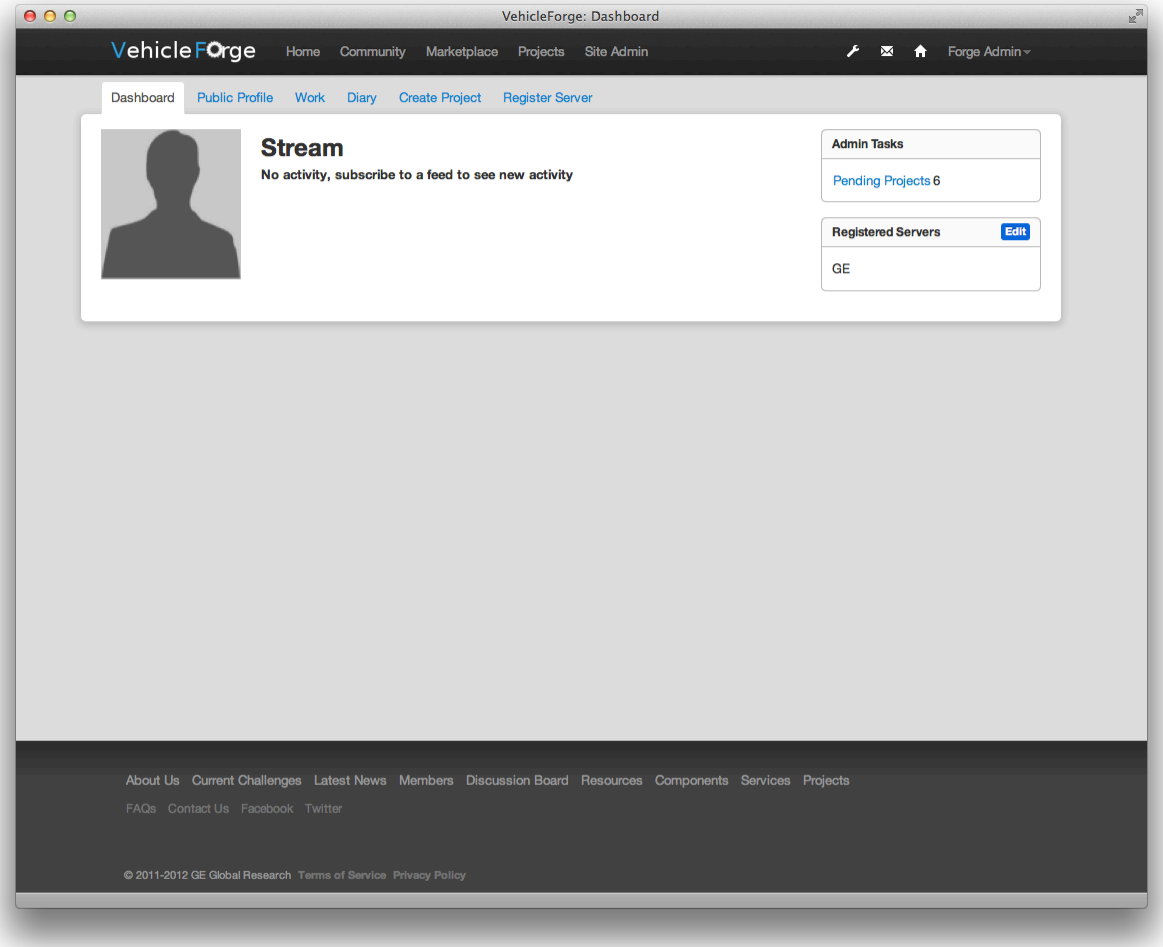
4.5. User Interface Design

The following sections contain screenshots of current and proposed user interface designs that went into the development of the vehicleforge website.

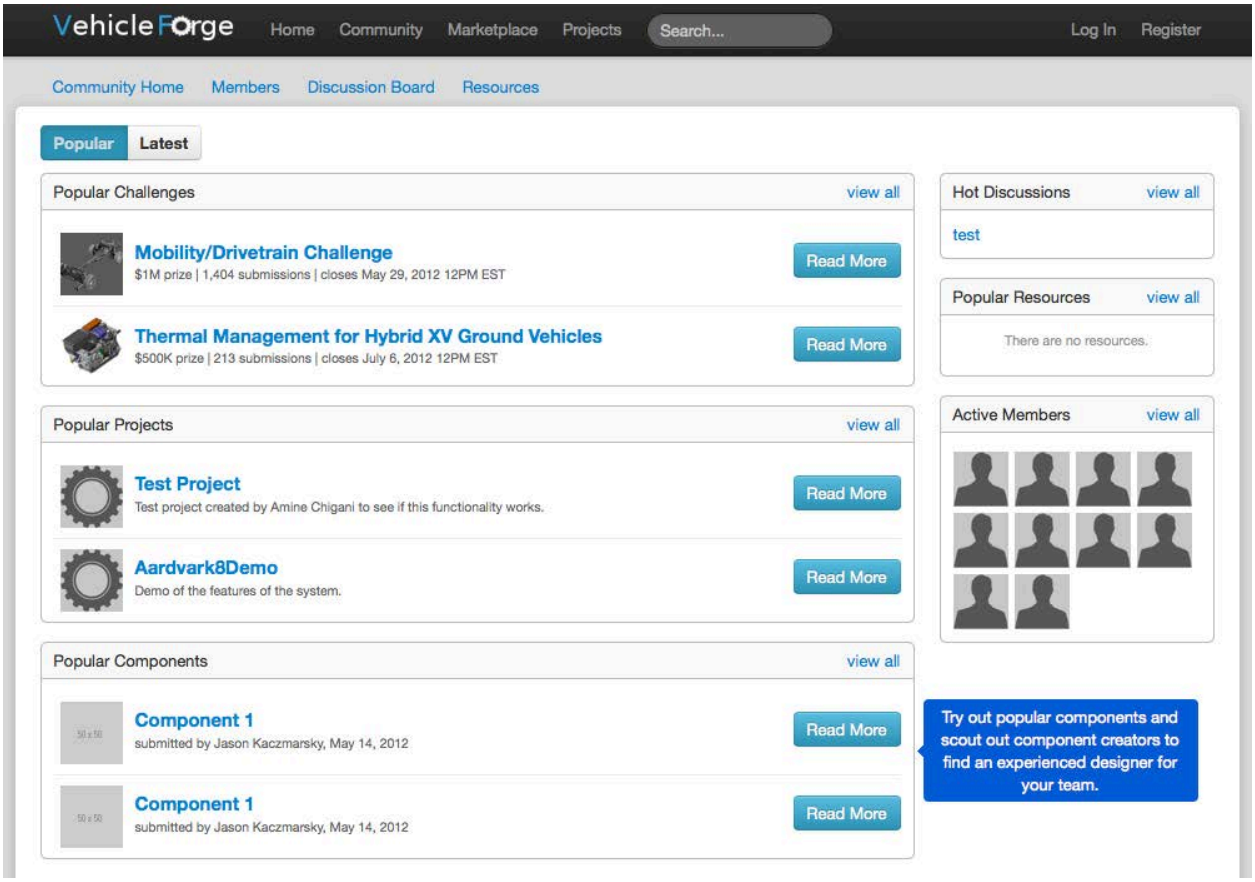
4.5.1. Home Page



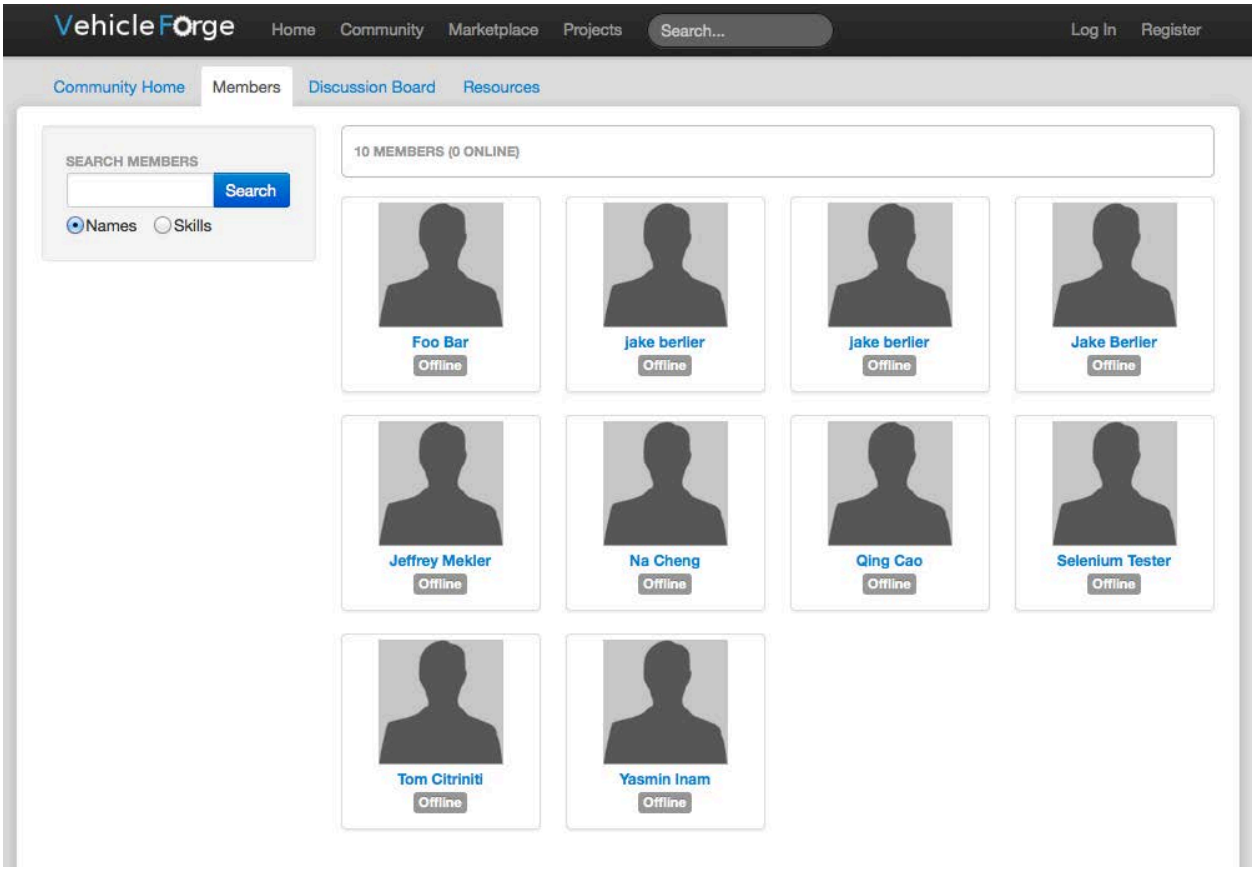
4.5.2. Dashboard



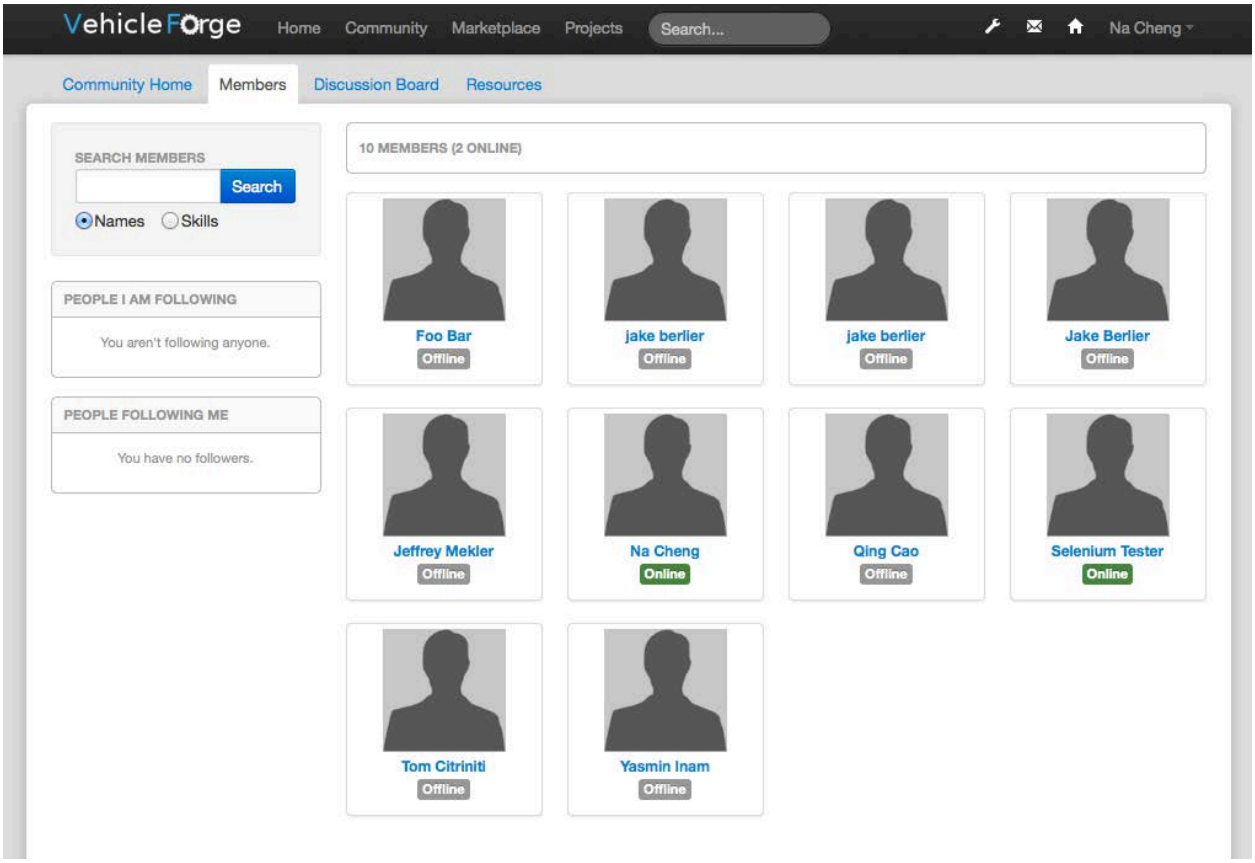
4.5.3. Community Home Page



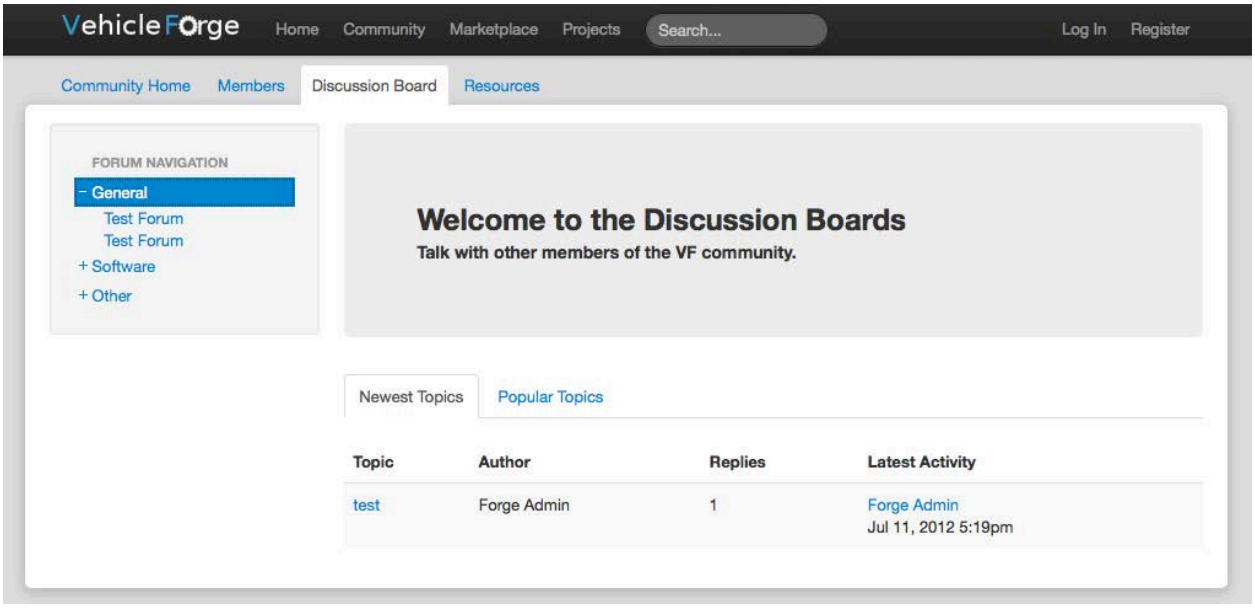
4.5.4. Members Page (before Login)

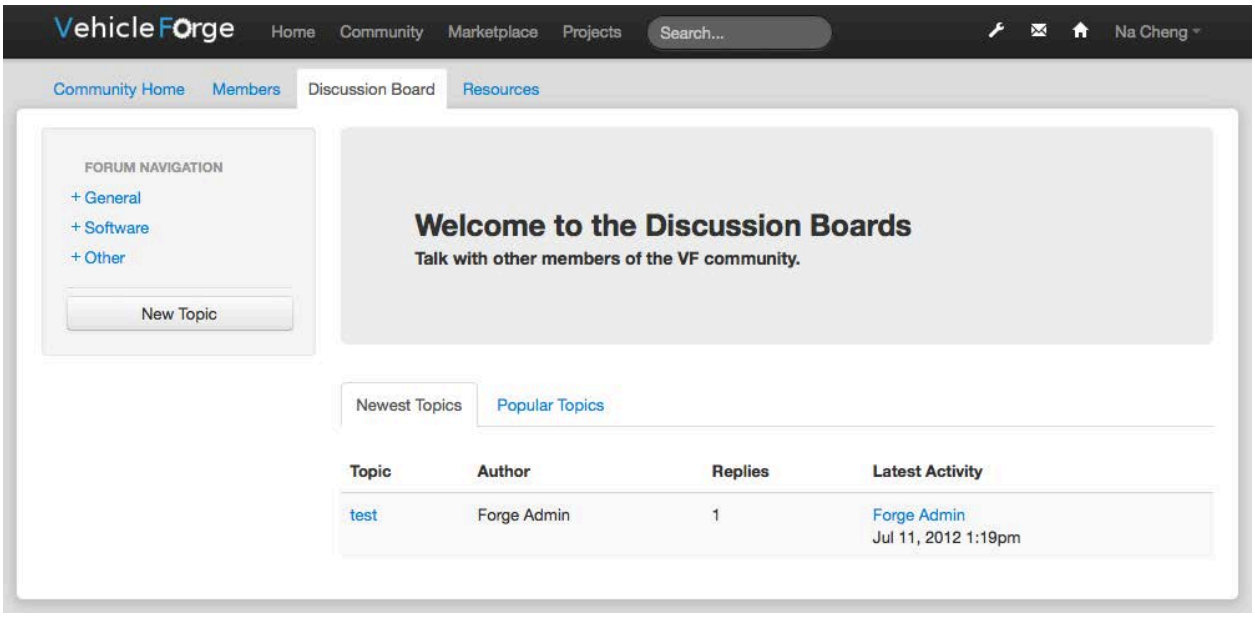


4.5.5. Members Page (after Login)

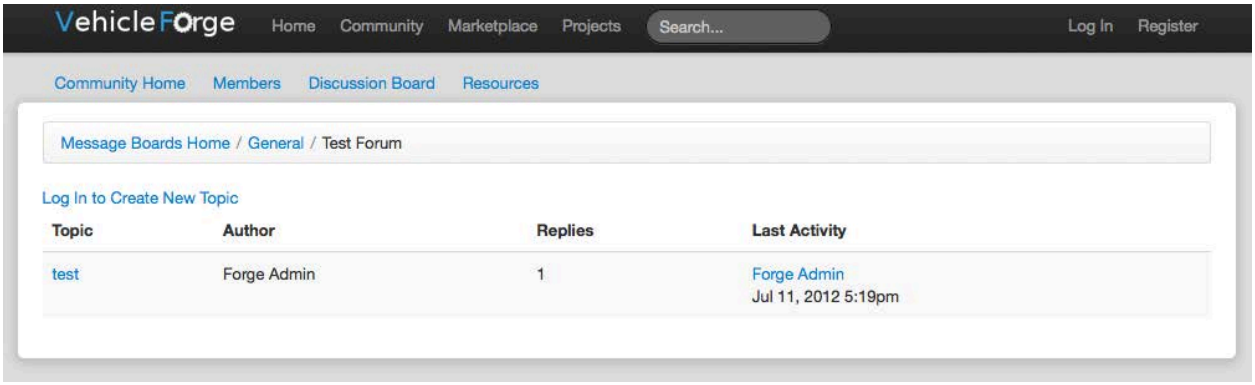


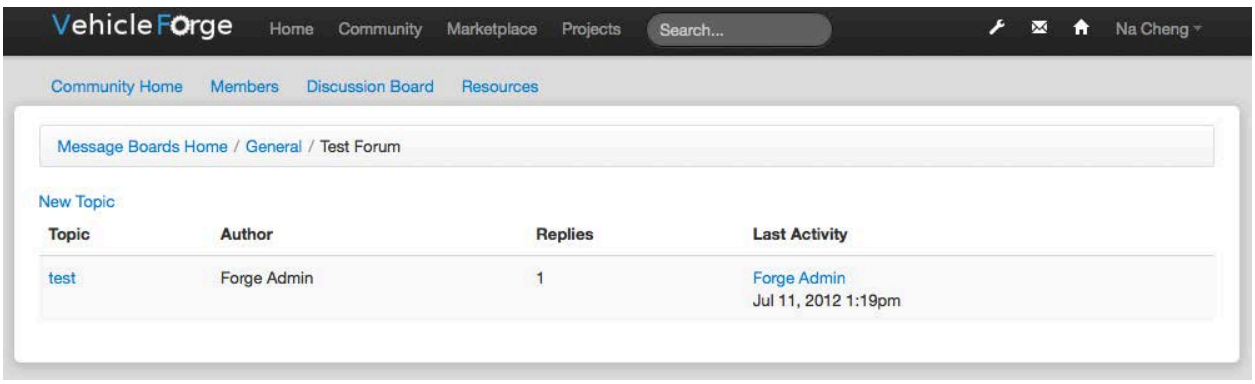
4.5.6. Discussion Board: Home (before/after Login)



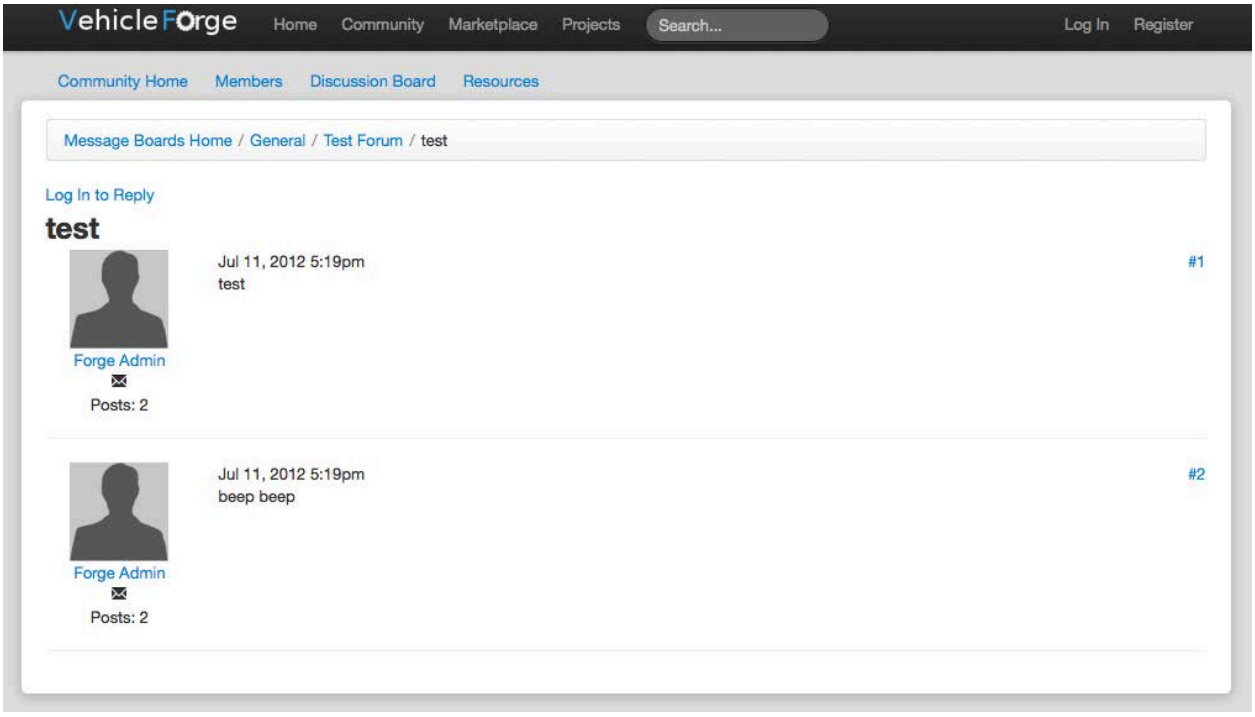


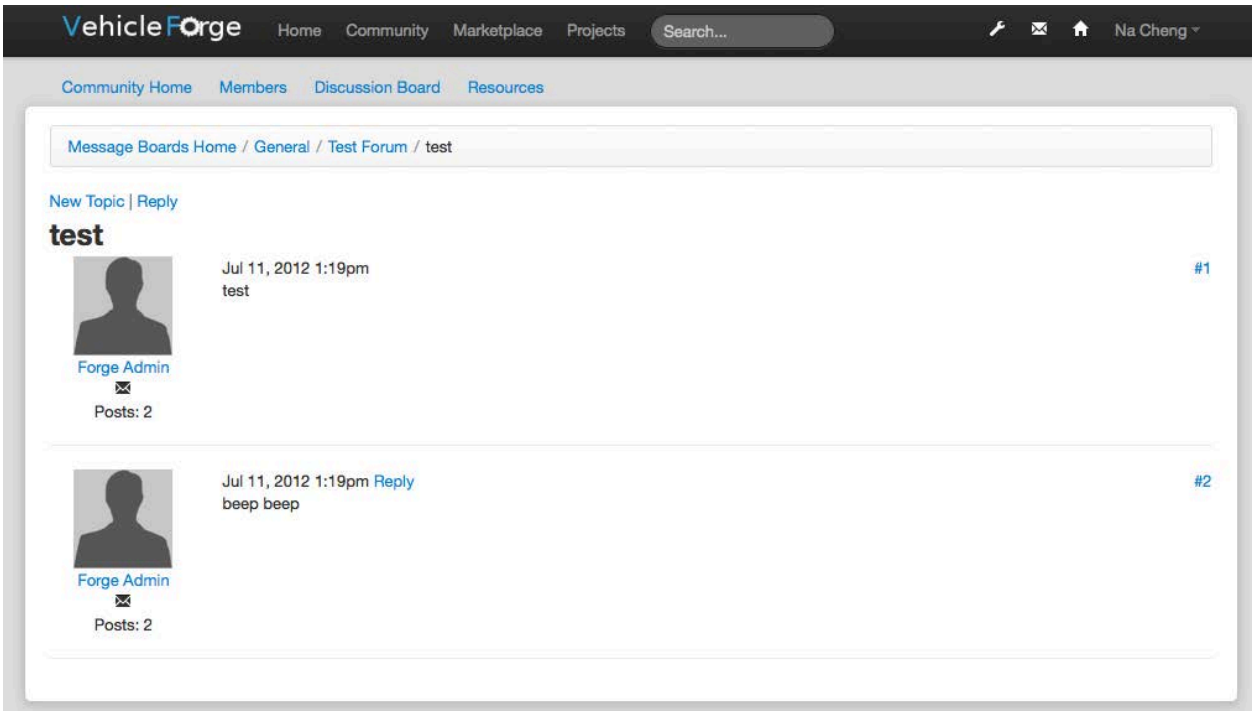
4.5.7. Discussion Board: Forum (before/after Login)



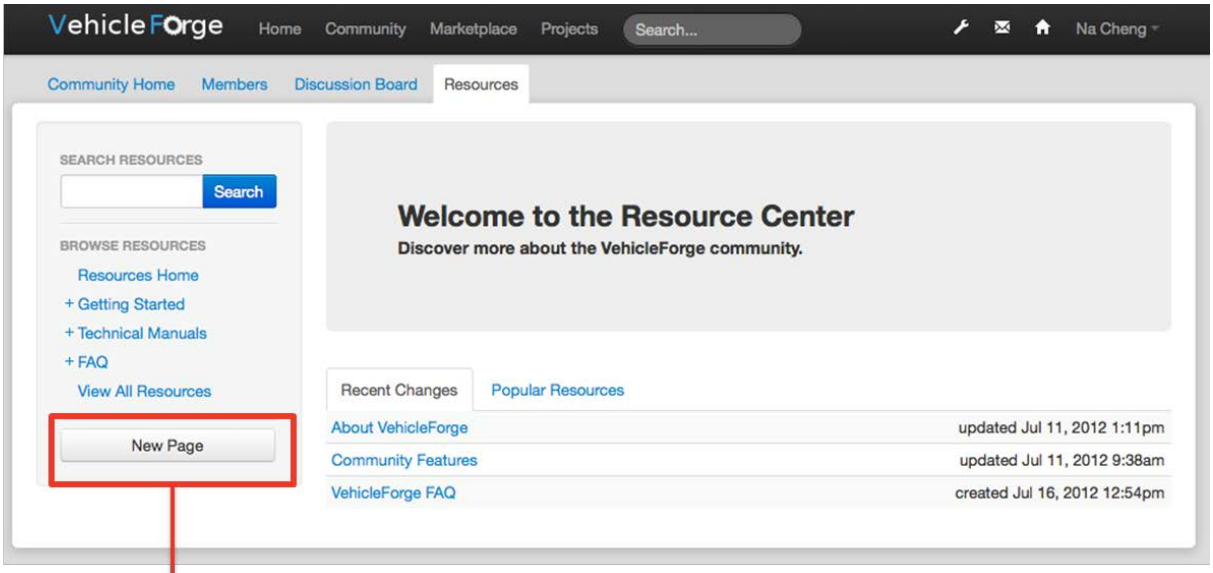


4.5.8. Discussion Board: Topic (before/after Login)





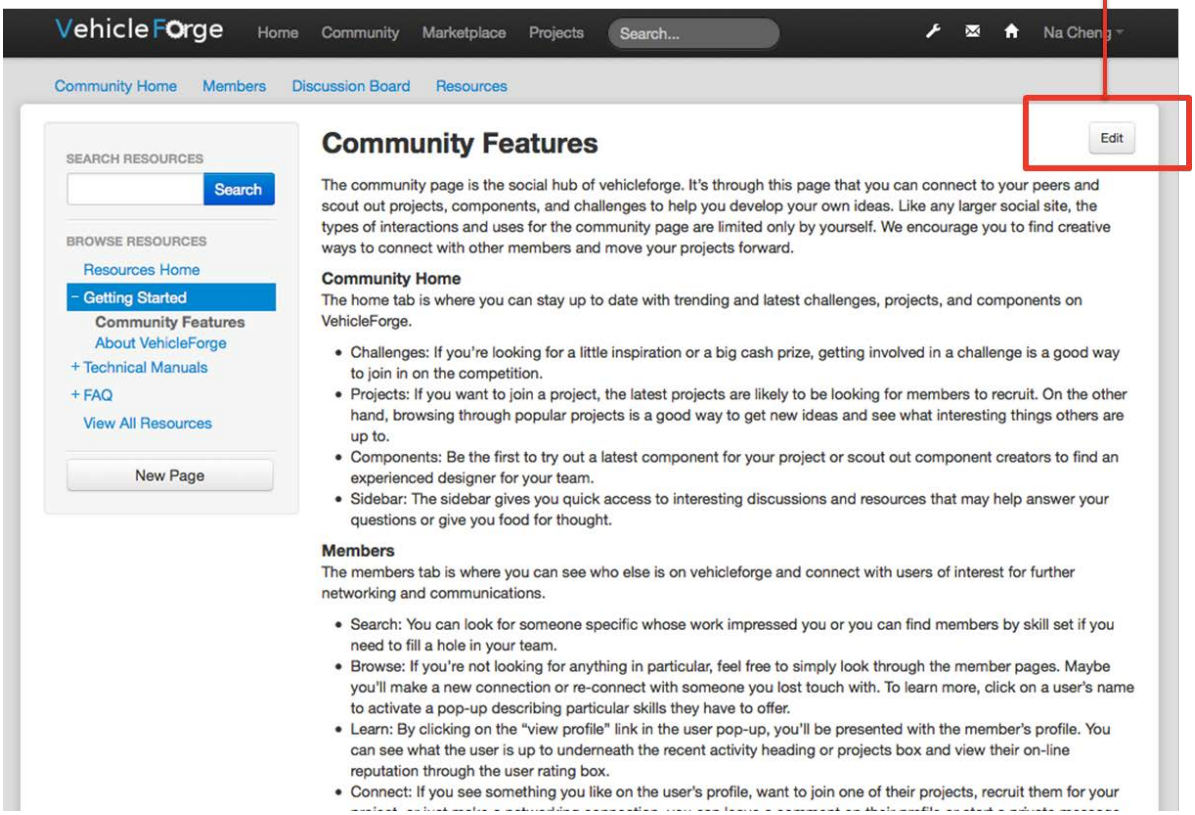
4.5.9. Resources Home



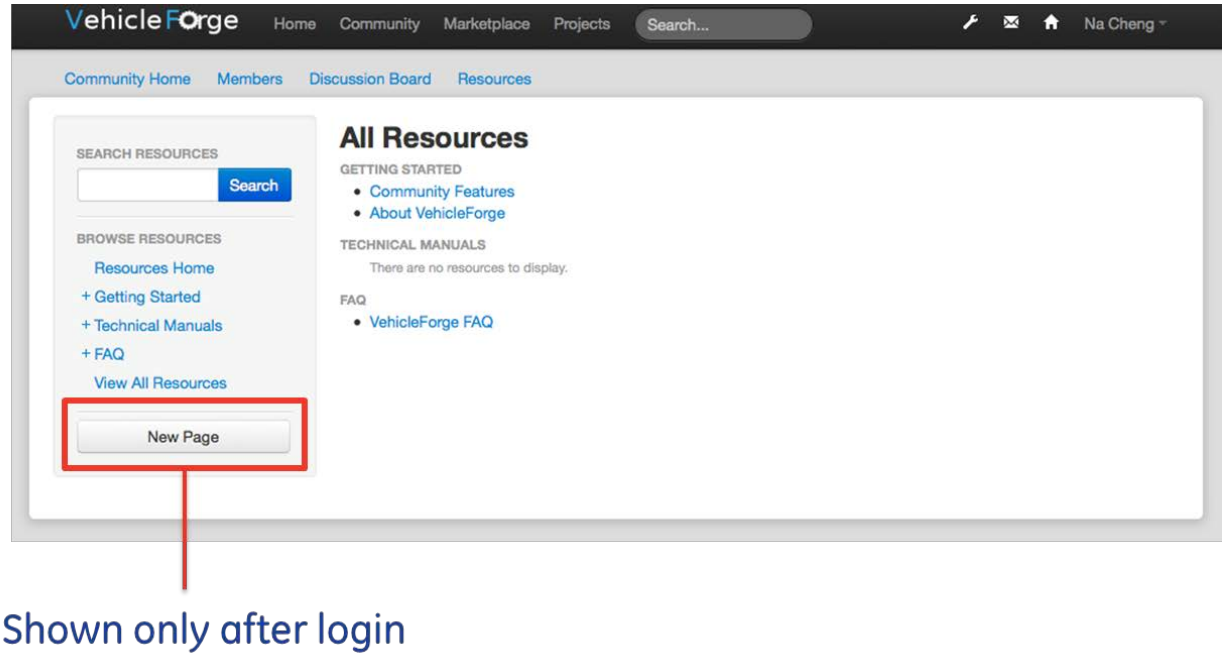
Shown only after login

4.5.10. Resources Page

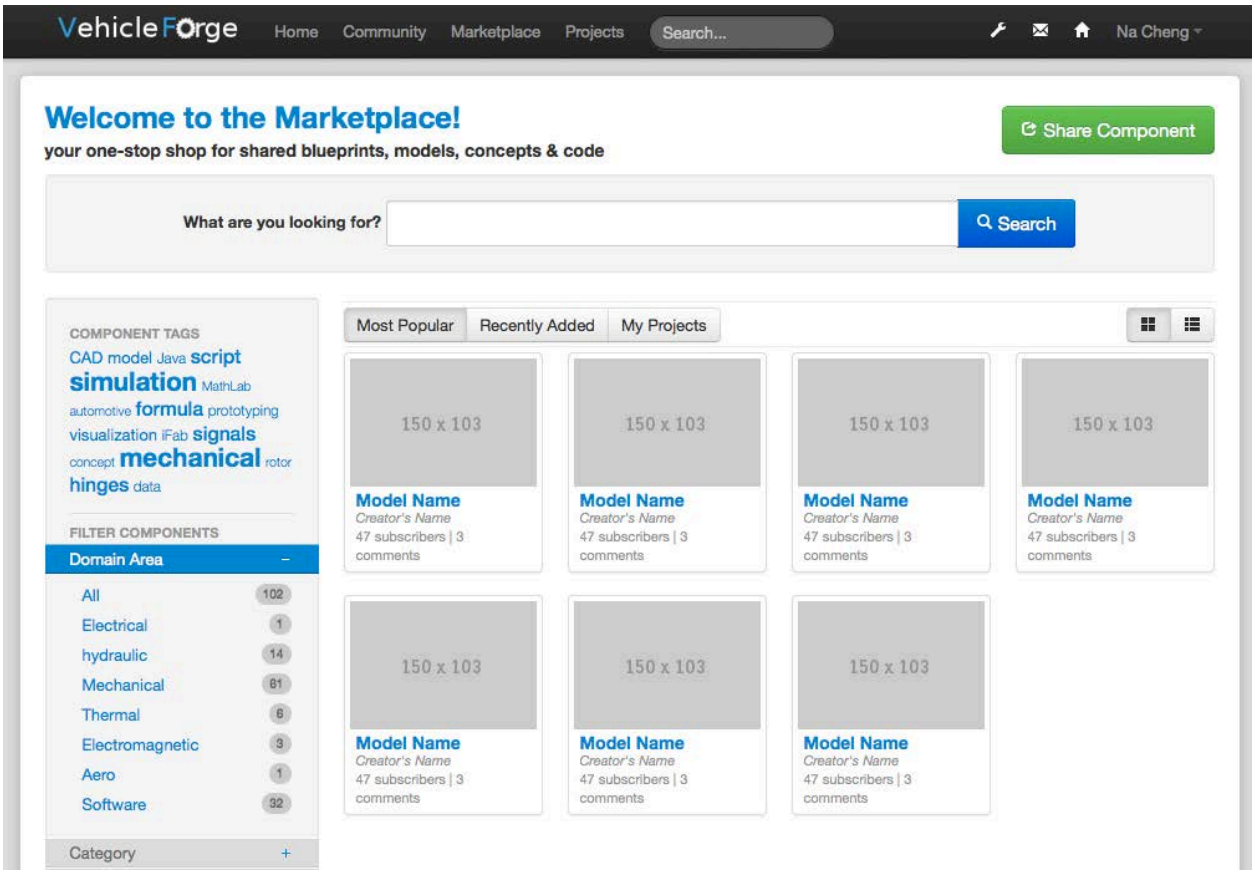
Shown only after login



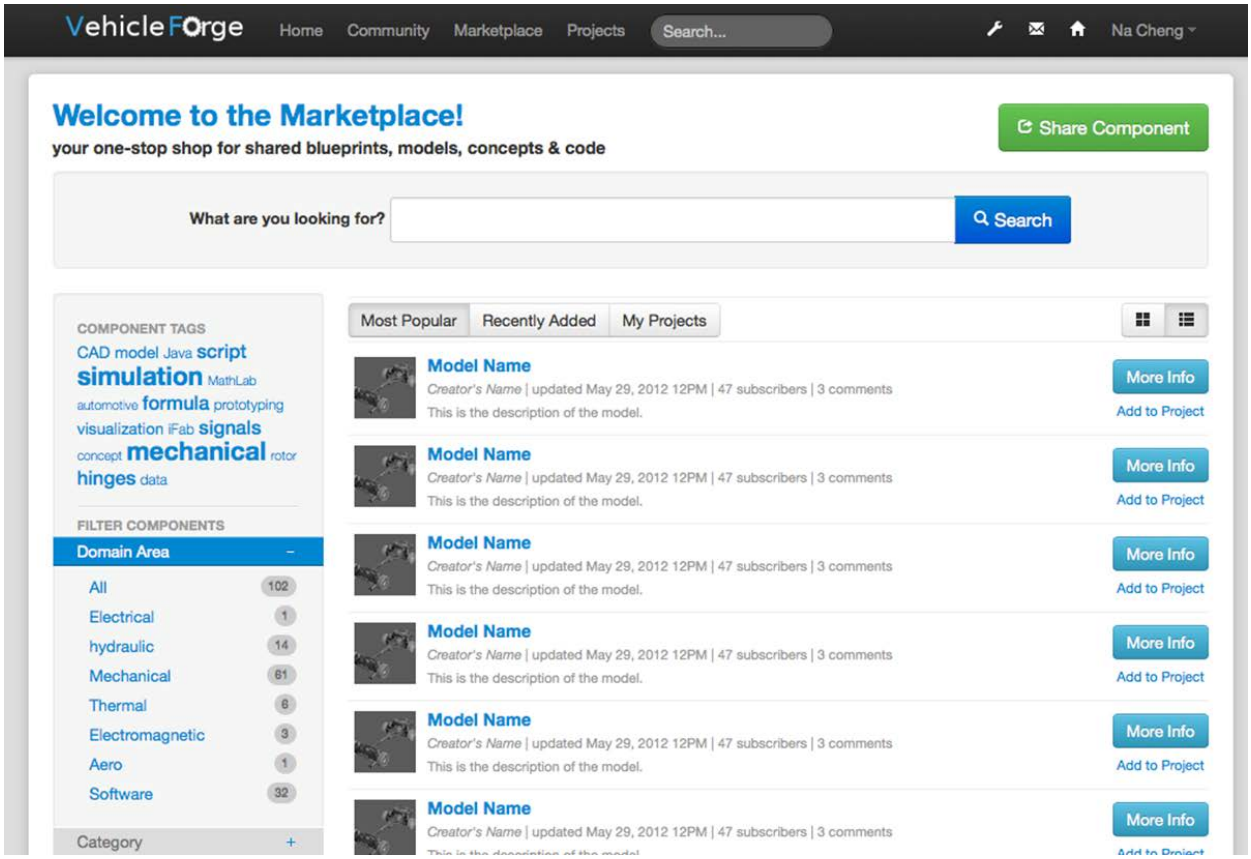
4.5.11. Resources Alternative: View All



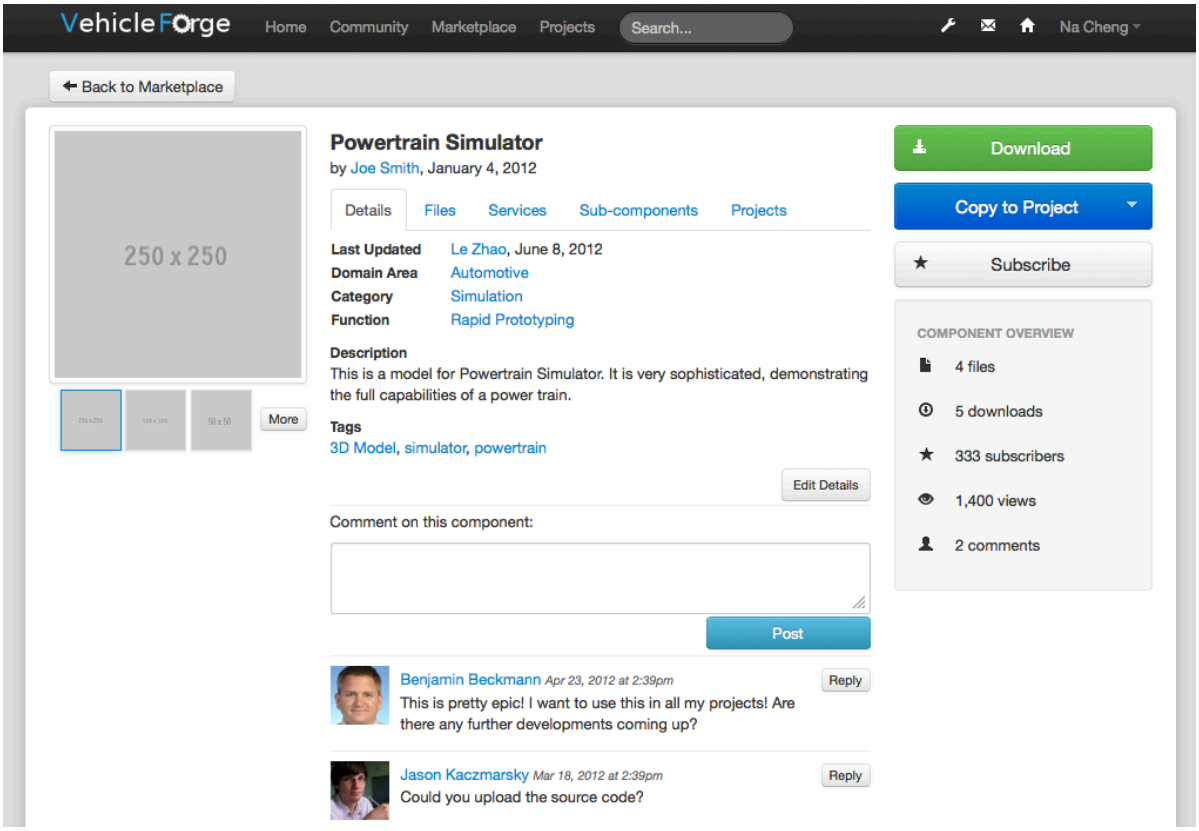
4.5.12. Marketplace

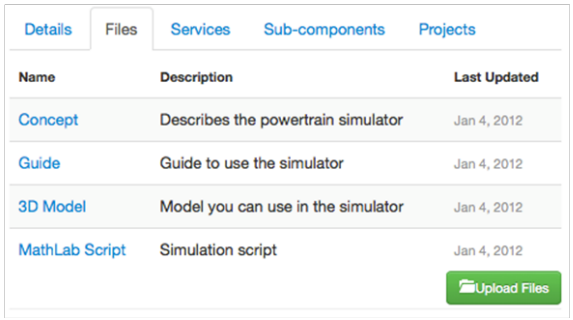


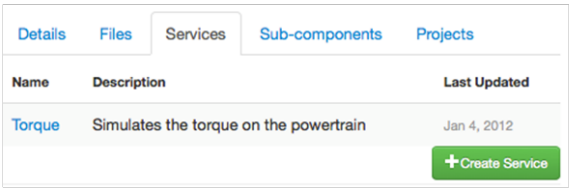
4.5.13. Marketplace (Alternative View)

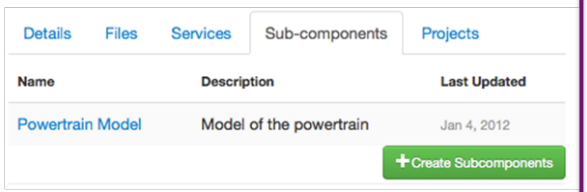


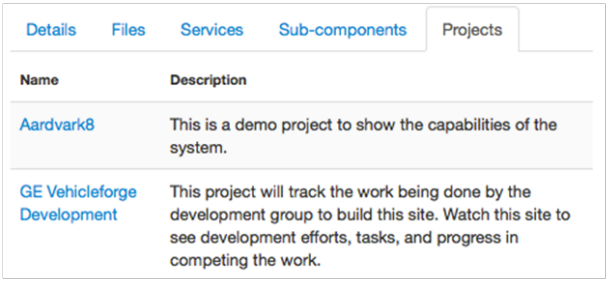
4.5.14. Component Page











5. IMPORTANT FINDINGS AND CONTRIBUTIONS

5.1. Contributions

In this project, a web-based collaborative crowdsourcing environment has been developed to democratize the design process of complex CEM systems. The CEED platform is constructed to achieve six goals:

1. Provide a collaborative design environment where CEM systems can evolve.
2. Address system-level integration of components represented by cross-platform, multi-domain, multi-physics models, analysis, and simulations with a distributed, declarative, and emergent integration paradigm.
3. Attract a crowd of productive experts, non-experts, and companies to a cooperative and rewarding design ecosystem.
4. Democratize the hardware design process by providing tools, test environments, and reiterative constructive criticism that drives selection.
5. Facilitate design-cycle incorporation of real-world performance feedback received from dynamic, competitive, or hostile environments.
6. Enable IP protected sharing in a collaborative environment for sustainable business models.

The CEED platform has integrated project hosting and management, an integrated simulation engine, distributed service marketplace, collaboration, security, search, web analytics, and user experience components based on customization and extension of existing open source solutions. Through these constructs, benefits in the context of crowdsourcing hardware design are being enabled, as described in Table 5:

Table 5. Key elements of the CEED platform

Key Elements	Benefits
Project hosting and repository	• Allow geographically distributed project development
Distributed service marketplace	• Sharing models and resources as services • Lower entry barrier • Rapid dissemination of technology development
Integrated simulation environment	• Modular design reuse • Allow integration of computational processes and capabilities
Crowd-oriented design and synthesis activities	• Democratize design and manufacturing • Collaboration through social networks • Continuously seed, sustain, and grow the hardware design crowd
Sustainable business model (open, proprietary, classified)	• Protect IP core • Bring suppliers and customers closer • Commoditize low value activities
Information assurance and certification	• Protect against malicious contribution • Protect data while supporting availability

5.2. Important Findings

Finding #1: Integrated simulation capability is needed in addition to a forge

Establishing a robust project hosting and model repository fulfills many of the requirements for supporting collaboration. However, the overarching goal of democratizing CEM design requires highly responsive modeling and simulation systems that move customers and suppliers closer together, allowing for rapid creation, validation, and delivery of products that closely match individual preferences. To that end, a project hosting and model repository only solution is limited.

One of the salient features of the CEED platform is a simulation "engine" (DOME) that contributors use to plug in and test simulated components in an IP protected fashion. Users can attach simulation services to explore the behavior of complex systems, and to predict problems earlier to get a better design faster. In addition, although through META and iFAB DARPA is releasing a new set of design/manufacturing tools to be available for use by the general design community, there are still many computer-aided design tools being used that are difficult to use and expensive. With DOME, the vehicleforge.mil program will allow solo inventors or small teams to tap into those capabilities.

Finding #2: Marketplace as a construct for sustainable crowdsourcing

A collaborative environment allows designers to team up to develop hardware components concurrently. It also promotes an active evolutionary design process capable of sourcing desired components. Interested members of the crowd can test shared components and collaborate through the marketplace in the system. The openness of the marketplace will allow input from a wide range of contributors with varying skill levels. Some contributors will be experienced model designers who rigorously test a model before making it available in the marketplace. Others will be less experienced designers who do not have the time or expertise required to test their contribution. When these models are contributed to the marketplace, they will experience market pressures that will distinguish well-designed models from the rest.

As the marketplace evolves, the models in the marketplace will increase in complexity and it will become more competitive. Individual models will compete to be integrated into other models. The competition among models will encourage model contributors to improve their designs to suit market needs. Over time, lower-level models will become more stable and full-featured higher-level integrated models will emerge. The competition in the marketplace will lower the costs required to design and integrate models, which will drive down the overall cost of development while improving outcomes.

In addition, the marketplace allows various business models to be deployed. Participants can be compensated for the models/data shared on the marketplace, and for providing reviews or testing services, etc. Using the service marketplace, product developers, small or large, can flexibly subscribe to and inter-relate services through appropriate computer-mediated interactions, building service network models that embody the capabilities of a product development organization.

Finding #3: IP protection mechanism during crowd collaboration

The acceptance of the marketplace as a viable location to search for and find high-quality model services is enhanced when proprietary models participate. The nature of a proprietary model is such that publicly sharing its intimate details decreases its value, and allows vulnerabilities to be found and exploited. Therefore, contribution of proprietary models to the marketplace is discouraged by a model's owner. However, the value of a proprietary model will increase as it is integrated into other successful models, as its designer can profit from integration. If the value of a proprietary model can be preserved and additional value can be added, due to integration into or with other models, then it is in the designer's interest to participate in the marketplace.

The CEED vehicleforge marketplace protects proprietary knowledge. When a model is published through DOME, its contents are encapsulated and only interfaces of desired functions are exposed. This allows developers with proprietary restrictions to share the model as a black box so that others can use the functionality of the model over the Internet. This is important because it enables the inclusion of proprietary models. It allows companies with intensive design and manufacturing expertise to participate and contribute without giving away proprietary knowledge, and also allows them to benefit from collaboration with the crowd. This mechanism will also benefit individuals and small businesses since they then could leverage the design services that are beyond their own expertise and gain access to tools to develop new products. Therefore, the marketplace not only protects a proprietary model's value through encapsulation, but it can also increase its value by safely exposing it to a crowd.

Finding #4: vehicleforge CEED platform to support the AVM design process

The Adaptive Vehicle Make (AVM) program is–at its core–an exercise in the collaboration of multiple design and manufacturing disciplines. This includes META teams defining models, iFAB teams defining manufacturing processes, and vehicleforge teams supporting the democratization of design. One challenge of being part of the AVM performer community is that many of AVM efforts are dependent on each other (i.e. C2M2L and META), but need to evolve on their own for a while due to the parallel nature of the program schedule. Existing collaboration channels mainly have idea-exchange focuses (i.e. PI meetings, and knowledge sharing through the share point.) Therefore, there is a potential opportunity for additional collaboration channel in the AVM community and ultimately the Fast Adaptable Next-Generation Ground Vehicle (FANG) challenge crowds.

DOME provides a platform upon which a community can seed, sustain, and grow a collection of crowd contributed models and services (Figure 6). The GE/MIT vehicleforge platform may be a good channel to enable the AVM performers to expose their models through a service marketplace. It can provide open access of all the AVM team's models/processes through DOME before its maturation, and provide more possibility for synergy.

Figure 6. DOME defines engineering constructs necessary to connect engineering and manufacturing tools

Finding #5: Culture challenges appose introduction of crowdsourcing in controlled corporate environments

Summaries of findings through voice-of-the-customer (VOC) meetings with GE engineers working on aircraft engine design:

- Compared with crowdsourcing and grass roots style approach to build systems, the engineers are more comfortable with the traditional "V" type of systems engineering. Most of the engineers' reasonability falls within component level; a cross-components systems level view is not shared by all. Chief engineers want control points of the design workflow, instead of fully automated.
- The CEED platform is a new way of sharing design data and models. In current practice, each design iteration results in many local copies of design data and artifacts where sharing is done through manual hand-off processes, causing mistakes and delays. Model repository is one method to address that. The engineers also found the CEED marketplace to be a productive way to share and search design models, history, and knowledge.
- Web-based platforms are the future trend for engineering software tools, but there is still a good population of engineers who prefer UNIX shell, command line environments, and other traditional methods. Therefore, the challenge is to provide a collaborative design environment solution in a platform agnostic way, and customize it to serve the needs of a mix of cultures.

6. IMPLICATIONS FOR FURTHER RESEARCH

Crowdsourcing platforms achieve success only to the extent that they are able to attract good individuals and motivate them to perform adequate work towards the end goals of the community. As a future work, the project team will explore a systematic way to build in incentive mechanisms and constructs to attract users and encourage contribution of high quality models to vehicleforge.mil.

7. STANDARD FORM 298, AUGUST 1998

See last page of this report.

8. TEAM BIOS

The following are the key personnel of the vehicleforge.mil team.

Dr. Qing Cao

Dr. Cao is a lead researcher in the Software Sciences and Analytics organization at GE Global Research. Dr. Cao has six years of industry R&D experience building solutions for intelligent analysis, design, and operation of complex networked physical and digital systems. Dr. Cao's research focuses on collaborative design methodology, integrated simulation, product development process, search, asset tracking, and other decisioning methodologies, with applications in broad business domains, including aviation, wind, energy services, healthcare, etc. Dr. Cao is active in her research community and organizes symposiums for the ASME Manufacturing Science and Engineering Conference. Dr. Cao received her Ph.D. in Mechanical Engineering from Massachusetts Institute of Technology in 2006, specializing in design methodology. She received her B.S. and M.S in Automated Control from Tsinghua University in China in 1997 and 2000, respectively.

Dr. David R. Wallace

Dr. David R. Wallace is a professor of Mechanical Engineering Director of MIT's Computer-Aided Design Laboratory and a MacVicar Faculty Fellow at MIT. Dr. Wallace obtained his Ph.D. from MIT in Mechanical Engineering in 1994. Since that time, he has taught design theory and methodology at MIT. He has been the principal investigator of several key initiatives in industrial design and product development sponsored by the National Science Foundation, Alliance for Global Sustainability, Ford MIT Alliance, MIT Center of Innovation in Product Development, and MIT Leaders for Manufacturing Program. His research interests include environmentally-conscious product design, integrated computer-aided design, industrial design and aesthetics, visual communication, and product design and new media education. Dr. Wallace has authored more than 50 scientific articles. He serves on the International Society of Industrial Ecology and American Association of Computing Machinery special interest group in Evolutionary Optimization.

Dr. Benjamin Beckmann

Dr. Benjamin Beckmann is a Computer Scientist in the Business Integration Technologies Lab at the GE Global Research. He received BS (2002) and MS (2004) degrees in Computer Science from Western Michigan University, and his Ph.D. (2010) in Computer Science from Michigan State University. His research in the areas of evolutionary computation, cloud computing, crowdsourcing, self-organizations, and artificial life are motivated by his desire to understand interactions among individual entities in a complex virtual, cyber-physical, and social systems.

Dr. Beckmann has established a strong track record as an independent researcher with a steady flow of publications ranging from the evolution of quorum sensing in self-replicating computer programs to adaptive logic for balancing of non-functional tradeoffs during system reconfiguration. His research has focused on evolutionary pressures to form communities and mold behavior. He has been an active contributor to open-source software platforms (including Avida, PECL, and the forthcoming vehicleforge) that support his research. His research has led to twenty refereed publications, and has been the focus of articles in The New York Times, New Scientist, and World of Intelligence (a French language magazine).

Mr. Thomas Citriniti

Mr. Thomas Citriniti is a Computer Scientist in the Software Sciences and Analytics organization at GE Global Research. Mr. Citriniti had over 20 years of experience building software products in the commercial market prior to joining GE. This work includes initial research, architecting, and delivering a new and existing software product in the GIS space. His focus over the last 8 years has been working with large fortune 500 customers to help architect their enterprise applications to ensure uptime and scalability.

Mr. Citriniti has authored publications and presented at conferences including SIGGRAPH, The Where in Business, Directions, Insights, and MapWorld. Mr. Citriniti also authored and taught a graduate-level course at Rensselaer Polytechnic Institute on 3D Computer Graphics and Scientific Visualization. This work focused on the presentation of real world phenomena using 3D simulation and multiple visualization methods. Mr. Citriniti has a BS from SUNY Cortland and a MS from Rensselaer Polytechnic Institute.

Mr. Jake Berlier

Mr. Jake Berlier recently started his first rotation in GE's Edison Engineering Development Program as a member of the Business Integration Technology lab at the GE Global Research Center in Niskayuna, NY. He received a MS in Computer Engineering from Virginia Commonwealth University (Richmond, VA) in 2011, and a BS in Computer Engineering from Miami University (Oxford, OH) in 2008. His areas of interest in research and technology include machine learning, high performance computing, and embedded system development.

Dr. Bouchra Bouqata

Dr. Bouchra Bouqata, Lead Scientist GE Global Research shall act as System Customization and Analysis Lead. Dr. Bouqata has been leading GE's efforts on artificial general intelligence and general autonomous intelligent systems with emphasis on human-brain inspired general learning (by experience and interaction), perception from real environment sensory inputs, general problem solving, reasoning (plausible, probabilistic, and case based), memory, language, and emotions. Her work focuses on developing intelligent distributed decision-making systems at the individual and collective levels of entity networks with high impact on GE businesses such as mobile asset management, healthcare (homehealth, teleheath, screening, prognostics, diagnostics, and chronic, disease management), and energy (grid anomaly detection). Dr. Bouqata has over 10 years of experience in the areas of machine learning, pattern recognition, multi-criteria clustering, artificial intelligence, data mining and modeling, knowledge discovery and capture, and statistics in applications as diverse as bioinformatics to financial engineering to logistics. Dr. Bouqata received her Ph.D. in Computer Science majoring in Artificial Intelligence and Machine Learning from Rensselaer Polytechnic Institute in 2006, her MS in Computer Science majoring in Artificial Intelligence at Al-Akhawayn University (Morocco) in 1999, and her BS in Applied Mathematics in Statistics at Adbel-Malek Essadi University (Morocco) in 1995.

Dr. Na Cheng

Dr. Na Cheng is a collaboration researcher at the GE Software Center of Excellence, GE Global Research. Her research focuses on social collaboration, social networks, data analytics, and data mining. Dr. Cheng received her Ph.D. in Electrical Engineering and Computer Engineering from Stevens Institute of Technology in 2012, specializing in problems in text based online media forensics.

Dr. Amine Chigani

Dr. Amine Chigani is a Computer Scientist in the Business Integration Technologies Lab at GE Global Research. His research focuses on system of systems engineering, software architecture, quality attributes, and service-oriented computing. Prior to joining GE Global Research, Dr. Chigani worked as a Visiting Scientist at Carnegie Mellon's Software Engineering Institute helping the Department of Homeland Security develop integration strategies to guide the adoption of the Commercial Mobile Alert System by emergency alert originators nationwide. He led the development of an integration strategy framework currently used to develop these strategies. Dr. Chigani has publications in the International Journal of System of Systems Engineering, IEEE Software Engineering Workshop, SEI Software Architecture User Network Conference, IEEE Conference on Software Engineering Education and Training, and International Conference on Software Reuse. Professionally, he is a member of ACM, IEEE, SEI, and ASEE. He holds a BS (2003) in Computer Science from Radford University, and MS (2007) and Ph.D. (2011) in Computer Science from Virginia Tech. He also holds the Software Architecture Professional Certificate (2010) from the SEI.

Ms. Hannah Deering

Ms. Hannah Deering is a User Experience Design intern in the GE Software Center of Excellence division of GE Global Research. She is a graduate student in Human-Computer Interaction at Iowa State University. Her research focuses on user-centered design, interface design, accessibility, and usability especially as they relate to modern web applications. She received a BS in Computer Science and BA in Art and Design in 2011, with a focus on digital media.

Mr. Andrew Liscomb

Mr. Andrew Liscomb is a Senior Software Engineer with Consilium1. He has over 20 years of experience in a variety of roles in commercial software development organizations. His work includes design and implementation of data conversion systems, quality assurance systems, product delivery and installation software, software process improvement efforts, as well as a J2EE web services toolkit, and B2B data reporting systems. He is a Certified Scrum Master, and has worked using the Scrum framework for several years.

Mr. Liscomb has presented at MapWorld and at local Java Developer Network meetings, and he has a BS from Clarkson University.

Mr. Jeff Mekler

Mr. Jeff Mekler is an engineer and designer at MIT, where he is completing MS degrees in Mechanical Engineering and Technology and Policy Studies. Building upon previous experiences creating software tools for systems engineers, Mr. Mekler helped design the vehicleforge user experience and assisted in feature development. Mr. Mekler's research examines the benefits and limitations of crowd-sourced engineering design. In his spare time, he enjoys skiing, hiking, and photographing the outdoors.

Mr. Adam Myatt

Mr. Adam Myatt is a Principal Technologist at GE Global Research. He obtained a BA in Computer Science from the State University of New York at Potsdam. With over 10 years of software development experience, he has established a reputation as an industry expert. Adam has published several books on software development tools and technologies, spoken at industry conferences, such as JavaOne, and participates in software evangelist groups, such as the Net-Beans Dream Team. In his role at GE Global

Research, Adam provides enterprise level architecture analysis and solutions for cross-industry collaboration with GE businesses such as Aviation, Energy & Power Generation, Healthcare, and Financial/Investment. His role also focuses on setting long-term strategies and documenting standards and processes for software development programming languages, tools, and related technologies. Additionally, Adam mentors global development teams throughout the company on tools such as CVS/SVN, bug/issue trackers, IDE's, and software project management tools.

Ms. Ariadne Smith

Ms. Ariadne Smith is a graduate student in mechanical engineering and engineering systems at MIT. She graduated in 2010 with a degree in Mechanical Engineering from MIT, having completed internships in venture capital, consumer electronics, medical device, and energy efficiency companies. She is interested in entrepreneurship and new forms of product development. Outside of academics, she enjoys swimming, running, cycling, and playing guitar when she has time.

Mr. Richard Welty

Mr. Richard Welty is a Software Engineering Consultant at Logic Technology, Inc. in Schenectady, New York. He has 30 years of professional experience in Software Development, System and Database Administration, and Network Engineering. Mr. Welty is currently serving as President of the U.S. Chapter of the OpenStreetMap Foundation. He has twice been Vice President of Engineering at Network Startups in the Capital District of New York.

Mr. Welty's publications and presentations include articles included in DARPA Image Understanding Workshop proceedings and more recently at GIS Day at the State University of New York's School of Public Health. He has taught a graduate level course in Operating Systems at the State University of New York. Mr. Welty has a BS in Computer Science from Rensselaer Polytechnic Institute.

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14. ABSTRACT

GE Global Research and Massachusetts Institute of Technology jointly developed a crowdsourcing platform to support DARPA's "vehicleforge.mil" program to revolutionize modern-day design and manufacturing. Our vision is to build a crowd-driven ecosystem for evolutionary design (CEED). It will connect data, design tools and simulations in a collaborative environment to accelerate the design of highly complex industrial systems. Such an environment allows designers to team up to develop projects concurrently. Developers from different spaces will be able to form design communities and create a common project space. This space will allow them to manage processes as a team and track changes and updates on their project. Furthermore, the CEED platform provides a marketplace where contributors can choose to expose their ideas to the public either as open source or as IP protected services." The exposed design models, or models available for review in this open community, will experience market pressures that ultimately allow for the best designs to emerge. The CEED platform also embeds social media connections to maximize crowd engagement.

15. SUBJECT TERMS

crowdsourcing, collaborative design, ecosystem, service marketplace

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